A TWO DIMENSIONAL STUDY OF A LOUVRE TYPE DUST SEPARATOR

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James Carl Matheson, Jr.

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SYMBOLS

A - Area

$\angle B$ - Blade angle

C - Coefficient of discharge of orifice

C_1 - Dust concentration, initial - pounds of dust per pound air

C_2 - Dust concentration, blowdown

C_3 - Dust concentration, clean air

D - Diameter

$\mathcal{E}$ - Efficiency

f - Function

$\angle F$ - Face angle

G_1 - Dust flow rate, initial - pounds per second

G_2 - Dust flow rate, blowdown

G_3 - Dust flow rate, clean air

h_s - Static pressure differential - inches water gage

h_1 - Pressure differential, orifice 1 - inches water

h_2 - Pressure differential, orifice 2 - inches water

h_3 - Pressure differential, orifice 3 - inches water

K - Flow coefficient including velocity of approach correction

L - Length

P - Pitch

r - Radius, variable

R - Radius, fixed

S - Blade spacing

SYMBOLS (Continued)

T_d - Dry bulb temperature - degrees Fahrenheit

T_w - Wet bulb temperature

T_s - Stagnation temperature

V_1 - Initial velocity

V_2 - Velocity in blowdown duct

w_1 - Rate of flow of initial air - pounds per second

w_2 - Rate of flow of blowdown air

w_3 - Rate of flow of clean air

ρ - Air density - pounds per cubic foot

β - Ratio of orifice diameter to pipe diameter

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SUMMARY

A louvre type dust separator of rectangular cross-section was designed and built for the purpose of studying the separation in two dimensional flow. Air meters were provided in the approach and exit ducts, and filter bags were included in the exit circuits to collect the dust for weighing. Transparent "Lucite" cover plates were fitted to the separator.

The performance of the separator was observed at various rates of initial air velocity, percent blowdown air, and at various settings of the louvre face and blade angles.

It was observed that the effect of the angle of the louvre face was very pronounced. The separation reached a maximum at face angles of from 15 to 22 degrees for every value of blade angle, initial velocity, or blowdown percent. A comparison of this optimum and the optimum range for three dimensional, or cone shaped, separators led to the conclusion that it was not necessarily the angle of incidence of the air stream that was the important factor in the geometry, but the rate of reduction of cross-sectional area available for flow.

The effect of blade angle on the separation was slight. The trend was toward higher efficiency of separation at the smaller blade

angles. No correlation was found between separation efficiency and the total angle between the louvres and the inlet air stream.

The separation increased with increasing percent blowdown air, but not in the same proportion. It was concluded that the efficiency of operation was considerably higher at low blowdown rates.

The effect of initial velocity was small. These data scattered somewhat, but showed a trend toward higher efficiency at higher velocities. The results were not too conclusive, however, as the range of variation of initial velocities was limited.

I. INTRODUCTION

The louvre type dust separator is a relatively recent development in the field of mechanical dust collection. It has not yet attained extensive application, and has received little discussion in engineering literature. There are no design data or performance characteristics for louvre dust separators cited in engineering texts or handbooks, or, for that matter, any mention of the existence of this type of collection equipment.

Louvre type dust separators are manufactured both in England[1] and the United States,[2] where they are advertised as "Aerodynamic Dust Separators." The manufacturers claim extremely high dust collection efficiency for their equipment, along with compactness of size with high capacity, absence of erosion, low resistance to air flow, and constant efficiency irrespective of the size of the installation. The last claim is a particularly powerful one, as reduced efficiency in large "Cyclone" type separators is the chief disadvantage of that very popular design.

The filter elements of the separators manufactured in this country and in England are very similar, if not identical, being fabricated of a single louvred sheet and rolled into the form of a cone. In the Soviet Union the separator has been applied in a form similar to that of the model separator with which this study deals.

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[1]Musgrave and Company, Ltd., Saint Ann's Works, Belfast, Northern Ireland.

[2]Aerodyne Atlantic Corporation, 44 Wall Street, New York 5, New York.

Objective

The object of this investigation was to attempt to determine something of the mechanism of separation in louvre type dust separators by determining to what extent the angle through which the air must turn in order to pass the louvres affects the separation efficiency in a model separator with two dimensional flow.

Survey of Literature

The earliest discussion of louvre type dust separators to appear in the literature was a 1946 report by Zverev[3] of work started in 1943 in the U.S.S.R. During the period 1944-1945 a total of 16 various designs of the separator were tested at the laboratory for gas cleaning of the All Union Institute. The design illustrated in the article is very similar to that employed in the laboratory at the Georgia Institute of Technology, and its overall dimensions were of approximately the same order. The principle difference was in the shape of the blades. The influence of blade angle, percent blowdown, initial velocity, blade pitch, and particle size were studied. Curves were given by way of illustration. The findings of this study were either unknown to, or overlooked by later reporters.

The existence of a new and unusual type of dust collector operating on aerodynamic principles was reported in a British periodical[4]

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[3] N. E. Zverev, "Shutter Type Dust Collector of Small Dimensions," The Engineers Digest (American Edition), Vol. 3, No. 11, November 1946, pp. 557-59. (From Isvetya Vsesoyuznogo Teplotechnicheskoga Instituta, Vol. 15, No. 3, 1946, pp. 12-15.)

[4] "A New Aerodynamic Dust Collector," Engineering and Boiler House Review, Vol. 63, No. 9, September 1948.

in 1948. This report was of a very general nature of little value to the researcher, as was a 1949 article in Iron and Steel.[5] These articles were intended only to report a newsworthy item, and contained no information concerning experimental tests.

Linderoth's patent,[6] dated 1950, is of interest. It specifies "preferred embodiments of the design" arrived at by experiment, and under which the separator is presently manufactured. An analysis of the separation based on aerodynamic forces is included. It is not known to this investigator if the analysis is intended as a scientific explanation of the mechanism of separation, or whether it was arrived at through the difficulty of patenting any dust separator that professed to work on the centrifuge principle.

In 1950, Harwell[7] submitted a thesis at the Georgia Institute of Technology on an investigation of a louvre type dust separator. He investigated the effect of varying percent blowdown, inlet velocity, and dust concentration on separation efficiency. He also took pressure data in the separator. He found blowdown percent to be the only variable among those listed which appreciably affected the separation. He attempted an analysis of the variables thought to influence separation by the method of Dimensional Analysis.

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[5] "Dust Collection," Iron and Steel, Vol. 22, No. 3, March 1949, p. 98.

[6] E. T. Linderoth, United States Patent No. 2,506,273, May 2, 1950.

[7] C. W. Harwell, "An Initial Study of a Louvre Type Dust Separator," M. S. Thesis, Georgia Institute of Technology, School of Mechanical Engineering, 1950.

II. GENERAL DISCUSSION OF LOUVRE DUST SEPARATORS

The louvre dust separator, Figure 1, Appendix A, might be called, more exactly, a dust concentrator, since its operation is dependent upon continuously withdrawing a portion of the gas which entrains the greater portion of the initial solids. This withdrawal gas shall be designated blowdown, after Harwell.[8] The dust laden air which is introduced to the separator for cleaning is designated the initial air, and its dust, the dust input. The air that passes through the louvre face is called clean air, though it contains some dust.

The air entering the dust separator passes along the face of a louvred, or vaned, filter surface. The greater percentage of the air is passed between the louvres (clean air), and the smaller percentage continues along the louvre face and is withdrawn into a secondary circuit (blowdown). The vanes, or louvres, are normally set at some angle to the direction of the initial air flow such that the cross-sectional area for flow decreases in the direction of the blowdown circuit. The angle between the direction of flow of initial air and the filter surface is called face angle. The angle between the blades and the filter surface is designated as the blade angle. The sum of the blade angle and the face angle is seen to be the angle between a blade and the direction of the initial air stream. This is the total angle.

Commercial installations of louvre dust separators are usually provided with some means of separating the dust from the highly concentrated blowdown air stream, as an auxiliary cyclone, and a blower to

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[8] C. W. Harwell, "An Initial Study of a Louvre Type Dust Separator," M. S. Thesis, Georgia Institute of Technology, School of Mechanical Engineering, 1950, p. 2.

reintroduce this air to the upstream side of the louvre separator for recirculation. This eliminates the waste of the blowdown air, but involves some additional expense, both in initial and operating cost.

Efficiencies

It is well to introduce at this point a criterion of comparison of the performance of dust separators. Perhaps the best comparison of performance of various types of dissimilar separation equipment is found in the simple ratio of the weight of dust separated by the apparatus to the total weight of dust input; in this manner Harwell defined separation efficiency.[9]

$$E = \frac{G_2}{G_1}$$

where: G_2 = Dust flow into blowdown,

G_1 = Dust flow into apparatus.

This ratio increases with increase in percent blowdown air, entirely independent of the effect of the louvres. The separation efficiency would be zero with zero blowdown air, and 100 percent with 100 percent blowdown air. Harwell has pointed this out, and has corrected for it, calling the result "louvre effect."

Since it is desired to compare the effectiveness of the louvre separator at different values of percent blowdown, a different criterion has been chosen. Usually an increase in percent blowdown is undesirable, the ideal apparatus being one which would give a high percent separation

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[9] Ibid., p. 9.

with a low percent of the total air flow discarded as blowdown. Also there is no need to attribute to the effect of the separator that percent of the dust which would have passed into the blowdown circuit even if the louvres had not been present. With these factors in mind the efficiency has been defined as

$$\mathcal{E} = \frac{w_3}{w_1} \frac{(G_2 - w_2C_1)}{G_1}$$

where:
w_3 = Flow rate of clean air,
w_2 = Flow rate of blowdown air,
w_1 = Flow rate of initial air,
G_2 = Dust flow - blowdown,
G_1 = Dust flow - initial,
C_1 = Initial concentration.

The term w_2C_1, the product of the rate of flow of blowdown air and the initial dust concentration in the air, is seen to be that rate of dust flow which would pass into the blowdown circuit by virtue of splitting the air stream, regardless of the performance of the separator. A value of 100 percent for the new efficiency would indicate that the separator was removing 100 percent of the initial dust, and delivering 100 percent of the initial air as clean air. By substituting:

$$G_1 = w_1C_1$$

$$G_2 = w_2C_2$$

$$w_3 = w_1 - w_2$$

$$\mathcal{E} = \frac{(w_1 - w_2)}{w_1} \frac{(w_2C_2 - w_2C_1)}{w_1C_1}$$

and simplifying,

$$\mathcal{E} = \left(\frac{W_2}{W_1}\right)\left(1 - \frac{W_2}{W_1}\right)\left(\frac{C_2}{C_1} - 1\right)$$

another form of the expression for efficiency is obtained, and $\frac{W_2}{W_1}$ is seen to be the percent blowdown.

With given initial conditions of air and dust flow, and with an arbitrarily selected value of blowdown percent, the only variable in this equation is the concentration of dust in the blowdown air stream. It does not, therefore, seem to complicate the analysis.

In order to avoid confusion in terminology, the ratio G_2/G_1 will be called separation percent in this thesis.

III. THE PROBLEM

The problem of determining the mechanism of separation in louvre type dust separators is one of considerable complexity. Though it is possible to discuss here the probable mechanism, or mechanisms, it is beyond the scope of this work to attempt to present a complete mathematical analysis. No such analysis exists, as yet, and it is not probable that there will be one until the dynamics of fine particles, and the mechanics of turbulent flow in fluids, are more completely understood.

Harwell has described the separation as due to the "centrifugal force" on a particle as the air velocity is caused to make a "sudden obtuse angle" with its original direction.[10] It is perhaps easier to describe as the tendency of a particle to continue in its original direction due to its high inertia as compared with the inertia of the air stream. More simply, it is "easier" for the air to negotiate the sharp turn than it is for a particle which has a greater mass.

The frictional drag exerted on the particle by the moving air stream would tend to make the dust follow the curvature of the air stream, and pass through the louvres. The inertia force on the particle would act to keep it in its original direction. The resultant of the inertia force and the force of frictional drag would act on the particle in a direction to cause it to move toward the louvre face in a path of lesser curvature than that of the air stream, which might cause the particle to impinge upon a louvre and be reflected away from the face

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[10] C. W. Harwell, "An Initial Study of a Louvre Type Dust Separator," M. S. Thesis, Georgia Institute of Technology, School of Mechanical Engineering, 1950, p. 2.

and up into the air stream.

From this reasoning, it can be seen that the only chance that a particle might escape being passed through the louvres depends upon its impingement with a blade, as the particle is certain to have a trajectory directed toward, not away from, the louvre face. The velocity with which a particle rebounds after striking a louvre, and its direction, are dependent upon the angle of incidence of the collision. In any case, however, the particle would rebound with a lower velocity than the velocity it had before impingement, being in the limit equal to the velocity of impingement. With a lowered velocity the particle would become more influenced by drag forces, and less by inertia, and after a succession of impingements would have little chance of being separated. Also, it would seem that a large number of particles would strike the blades at an angle such that they would be reflected back into the air stream directed through the louvres.

Since the existence of the drag force, the inertia force, and their resultant are difficult to deny, and if the reasoning set forth is valid, it appears advisable to seek a third force component directed away from the louvre face. It is not at all certain that such a force exists, it is only a possibility. Certainly, its nature is not known.

Linderoth,[11] in his patent application, has attempted to visualize a resultant force on the particles directed away from the filter surface. He describes it as being due to a wave, or oscillatory, motion in the air stream along the louvre face. This may, or may not,

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[11]E. T. Linderoth, United States Patent No. 2,506,273, May 2, 1950.

be true. The analysis falls down when two forces, acting at different times, and at different positions of the particle are resolved simultaneously to give the desired resultant force.

IV. APPARATUS

The separator described here was designed to reproduce and extend the results obtained by Harwell in an earlier study at the Georgia Institute of Technology.[12] The size of the ducts, the blade width, height, and spacing, and other dimensions of the separator, were not arbitrarily chosen, but were selected to conform with the dimensions of the original separator.

The primary air was supplied by a Sturtevant seven-stage centrifugal blower. Air from the blower outlet passed two flanged elbows, one vertical and one horizontal, before entering a 60-inch length of 3-inch nominal diameter standard steel pipe. The air then passed through a thin plate orifice meter, and on into a 15-inch length of 3-inch standard pipe. The 60-inch length of pipe was considered sufficient to eliminate the necessity of providing straightening vanes upstream from the orifice.[13]

The 3-inch diameter circular cross-section was changed smoothly through a transition piece to the 2-inch x 3-inch rectangular cross-section of the entrance to a venturi section. Air from a separate compressor was used to introduce the dust into the primary air stream at the throat of the venturi section. This was to insure thorough mixing of the two streams in the highly turbulent diffuser length.

The dust laden air from the venturi was carried to the separator

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[12] C. W. Harwell, "An Initial Study of a Louvre Type Dust Separator," M. S. Thesis, Georgia Institute of Technology, School of Mechanical Engineering, 1950.

[13] T. J. Rhodes, Industrial Instruments for Measurement and Control (New York: McGraw-Hill Book Company, Inc., 1941), p. 240.

through an 8-inch length of 2-inch x 3-inch duct. The clean air stream, after negotiating a 90-degree turn to pass through the louvre face, entered a 6-inch length of 2-inch x 3-inch rectangular duct, and passed through a flanged rectangular elbow leading to the clean air dust collecting chamber. The blowdown air continued along its original line and passed into a 2-inch x 1-inch rectangular duct, and on through a flanged rectangular elbow into the blowdown dust collection chamber.

The blowdown air stream, after being cleaned in passing through a bag filter in the dust collecting chamber, entered a 1-1/2 inch diameter pipe containing an orifice meter. The air from the clean air dust collecting chamber was exhausted to the room through a 3-inch diameter pipe containing an orifice meter. The blowdown pipe terminated with a globe valve to control the blowdown flow.

The Separator

The separator section consisted of a 2-inch x 3-inch entrance dust, a 2-inch x 1-inch blowdown duct, a 2-inch x 3-inch clean air duct, connecting channels, cover plates, louvre assembly, and flow directors. The clean air duct was arranged at an angle of 90 degrees with the axis of the entrance duct and the blowdown duct. These three sections of 16-gauge sheet metal duct were connected by welding 3/8-inch x 2-inch x 16-gauge formed channel sections to form the outer walls of the separator.

The open bottom and top of the separator were covered with 3/8-inch thick plexiglass. The transparent cover plates were recessed around the edges to make them fit flush with the inside of the ducts when a 1/16-inch rubber gasket was installed and the covers were bolted tightly in place. The top cover plate was fastened with wing nuts to permit rapid removal and reassembly to change blade and face angles.

Three sets of louvres were used in this separator. They were made of 18-gauge brass sheet. The blades were 1/2 inch wide and 1-15/16 inches long. The pitch (P) was maintained constant for all sets of louvres, being 1/2 inch. Blade angles of 15, 22-1/2, and 30 degrees were employed. Each assembly contained eleven blades. The louvre assembly was held in place in the separator by the pressure of the cover plates. No other fastening was necessary.

The various face angle settings to be used in the study were scribed on the bottom cover plate. Wooden blocks, with rubber gaskets at top and bottom, were used to direct the flow in the length of the separator not covered by the louvre face.

Dust Feed

The dust feeding apparatus was the same as described by Harwell.[14] It consisted of a piston-cylinder arrangement, and was controlled by varying air pressure and the rate of lowering the piston.

Air from a compressed air tank was expanded through a pressure regulator, and introduced by a rubber tube to the top of the cylinder, above the piston. The air passed along a helical groove cut in the circumference of the piston, and entered the lower part of the cylinder tangentially. The lower part of the cylinder contained dust, and the air in blowing over it picked up some dust before passing out of the cylinder through a hole in the center of the piston and piston rod. The

[14] Harwell, op. cit., p. 14.

dust laden air was introduced to the primary air stream at the throat of a venturi section.

The rate of dust feed was controlled by lowering the piston with a small geared telechron motor. The regulator valve was set to keep the level of the dust approximately 1/4 inch below the falling piston.

Dust Collecting Chambers

Both air streams leaving the separator were passed through chambers containing bag filters where the dust was removed. These chambers were vertical cylindrical sheet metal cans with flanged tops into which Electrolux bags were fitted. The Electrolux bags were equipped with a rubber gasket at the open mouth which, when assembled, was pressed tightly between the flange forming the top of the can, and the flange on the rectangular elbow. The cans were fastened to the flanged elbows by bolts with wing nuts to facilitate rapid removal for weighing and cleaning the dust bags. A second rubber gasket was used between the flanges outside the bolt circle.

A horizontal length of 1-1/2 inch diameter pipe extended from the lower end of the blowdown dust collecting chamber at an angle of approximately 90 degrees with the inlet. In like manner a 3-inch diameter pipe extended from the clean air dust collection chamber. Both pipes were provided with orifices for the purpose of metering the air flow.

Air Meters

The air flow was metered at three points. The total flow was indicated by Orifice 1, located upstream from the point of dust feed between companion flanges at the end of a 60-inch length of 3-inch diameter pipe. The blowdown flow was metered by Orifice 2, in the 1-1/2 inch pipe leading from the blowdown dust collecting chamber. The clean air stream was metered at Orifice 3, in the length of 3-inch diameter pipe leading from the clean air dust collecting chamber. At all three points dust free air was being metered. All orifices were bolted between companion flanges, and were fitted with 1/16-inch rubber gaskets. Flange type pressure taps, 1 inch upstream and 1 inch downstream from the orifice, were used throughout. The design and calibration of the orifices is given in Appendix D, page 104.

A static pressure tap was provided upstream from the total flow orifice. A thermometer was also placed in the air stream at this point.

The differential pressure across the various orifices was measured with U-tube manometers calibrated in inches, and filled with water. A fourth water manometer was installed to measure the static pressure.

Other Equipment

A balance, accurate to 0.05 grams, was used to weigh the dust bags and dust cylinder. Other equipment consisted of a barometer, a wet-bulb and a dry-bulb thermometer, and a stopwatch.

V. TEST PROCEDURE

The apparatus was assembled, and the blower was started and allowed to run for a period of ten to fifteen minutes. This was to allow the air to come up to an operating temperature of approximately 10 degrees F. above room temperature, and to allow sufficient time for the dust bags to absorb or give up moisture to adjust to the humidity of the new day. The total flow was regulated at the blower inlet by means of a damper until the total flow manometer reading indicated the desired flow. The blowdown valve was then adjusted until the blowdown manometer indicated the desired blowdown flow rate. It was usually necessary to reset the total flow after changing the position of the blowdown valve. Readings were taken of the total flow manometer difference, the blowdown manometer, and the clean air manometer. The flow rates were read from the calibration curves, and a check was made on the calibration by the difference in flow rates as indicated by the different orifices. The blower was then stopped and the dust collecting chambers were disassembled.

The barometer reading was taken and recorded on a data sheet. The run number, and the blade angle and face angle were entered on the data sheet. The blowdown dust bag and the clean air dust bag were emptied, weighed on the beam balance, and their weights were recorded. They were then returned to their respective dust collecting chambers. The dust cylinder was disassembled, filled with dust, and weighed. After its weight was recorded the dust cylinder was reassembled.

As it was necessary to change face angle or blade angle, the wing nuts were loosened and the top cover plate was removed. The louvre set was arranged, and the proper wooden flow director was set in place. The cover was then replaced and tightened down. The dust collecting chambers were then reassembled and the wing nuts tightened.

The blower was started, and the flow was checked by noting the manometer readings. The separator and the dust collecting chambers were checked for leaks and tightened more securely, if necessary.

If everything was in order, the stopwatch was started, the secondary air valve to the dust feeder opened, and the telechron motor was started.

The left side and right side of the static pressure manometer, the total flow manometer, the clean air manometer, and the blowdown manometer were read and recorded in the order named. The stagnation temperature, and the wet- and dry-bulb temperatures were recorded.

The dust feed was watched closely during the run, as were the flow manometers. Any detectable variation was considered sufficient reason for throwing out that run and repeating it.

At the end of three minutes, as indicated by the stopwatch, the secondary air was shut off, the telechron motor was stopped, and the blower was shut down, in that order.

The dust collection chambers were immediately disassembled. The dust bags were removed, weighed, and the weights recorded. The dust cylinder was unscrewed, and dust collected in each bag was calculated. The difference in the weight of dust input and the total weight of dust collected in the bags was taken. If this value exceeded 0.5 grams the run would arbitrarily be repeated. Fortunately, this was seldom necessary.

This procedure was repeated for each run. Seven series of tests were made, 18 runs to a series, or a total of 126 runs. In the first four series the percent blowdown was varied from series to series while total flow was held essentially constant throughout. In any given series the only variables were face angle and blade angle. Three blade angles were used, and six face angles, giving 18 combinations of blade and face angle to form a series.

The last three series of runs, along with one series from the first set, were to determine the effect of varying velocity. Total flow was varied from series to series as percent blowdown was held approximately fixed.

VI. DISCUSSION OF RESULTS

Data for the experimental louvre type dust separator were taken in order to determine the effect of certain variables on the efficiency of the separation. These factors were by no means the only ones thought to affect the separation. However, the number of variables that could be investigated thoroughly was limited by the time available, and the scope of a work of this kind. The factors selected for study were blade angle, face angle, percent blowdown, and initial velocity.

Throughout the study an attempt was made to hold the initial dust concentration constant. This was very nearly impossible as it was difficult to control the rate of dust feed accurately with the dust feeder used. However, the effect of varying concentration was shown by Harwell to be very slight in the range of his study,[15] which was considerably larger than the range of variation observed here. The dust load was so low that the presence of the dust could not have conceivably affected the air flow. The physical dimensions of the dust feeding mechanism were too small to permit the use of higher concentrations. The feeder cylinder would hold only about 60 grams of dust, and, as the dust did not remain level in the cylinder, it was possible to feed only about 40 grams of dust into the apparatus during a run. The initial concentrations were of the order of 18 grains of dust per pound of air, or less than 2 grains per cubic foot. This is very low.

The difficulty in setting initial concentration at a desired

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[15] C. W. Harwell, "An Initial Study of a Louvre Type Dust Separator," M. S. Thesis, Georgia Institute of Technology, School of Mechanical Engineering, 1950, p. 28.

value after changing the air flow conditions made it necessary to perform all the runs required for given flow conditions before changing to a second set of flow conditions. The data are presented in Tables I and II, Appendix B. The pattern is easily discernible. Runs 1 through 72 were made at (as nearly as possible) the same conditions of initial velocity, in order to determine the effect of varying percent blowdown. These 72 runs were broken into four sets of 18 runs each. Runs 1 through 18 were performed at approximately 20 percent blowdown; runs 19 through 36 at 8 percent blowdown; runs 37 through 54 at 15 percent blowdown; and runs 55 through 72 were performed at approximately 30 percent blowdown. Each set of 18 runs was made up of three groups of six runs each, each group being for a different set of blades. The first group of six runs in any set of 18 consisted of varying face angle as blade angle was held constant at 15 degrees, the second group of six was at a 22-1/2 degree blade angle, and the third group was at a 30 degree blade angle; viz,

$\angle B$	15					
Run	1	2	3	4	5	6
$\angle F$	0	7-1/2	15	22-1/2	30	45

$\angle B$	22-1/2					
Run	7	8	9	10	11	12
$\angle F$	0	7-1/2	15	22-1/2	30	45

$\angle B$	30					
Run	13	14	15	16	17	18
$\angle F$	0	7-1/2	15	22-1/2	30	45

Runs 73 through 126 consisted of three points of varying initial air velocity, V_1. These, combined with runs 37 through 54, comprised four points of initial air velocity, for which blowdown was held constant at 15 percent. The four values of V_1 were, approximately, runs 37 through 54, 55 ft/sec; runs 73 through 90, 33 ft/sec; runs 91 through 108, 45 ft/sec; runs 109 through 126, 65 ft/sec; see Table III. The pattern of varying geometry was as described for the previous runs.

The effect of varying face angle on the efficiency of separation was observed to be a factor of the greatest importance; see Figures 2 through 22, Appendix A. These curves have blade angle as a parameter, each plot representing the effect of face angle for a single value of blade angle. All of the curves are concave downward with a maxima at some value between 15 and 22-1/2 degrees of face angle. The effect of face angle, as denoted by the curvature of the plot, is seen to be more pronounced at the lower values of percent blowdown, and less at the higher values. Figures 11, 12, and 13 are for a blowdown rate of 30 percent, and are very flat compared to the curves for lower blowdown percent.

It was originally believed that the important factor in the geometry of the separator might be the total angle through which the air must turn in order to pass through the louvres. This idea arose from the consideration of the inertia forces, and angle of incidence as presented in a previous section of this thesis. It is seen from the curves, Figures 2 through 22, that this is not the case. The total angle is the sum of the blade and face angles, and a plot of efficiency versus total angle would consist simply of shifting any curve (of efficiency versus face angle) a distance to the right equal to the value of blade angle shown. Blade angle shows a slight effect on the height of the maxima of the various curves, but no apparent effect on the position of the maxima in the x direction, as all maxima are found to be somewhere in the range of 15 to 22-1/2 degrees of face angle. The variation of efficiency with blade angle showed a slight trend toward increasing efficiency with decreasing blade angle, but only for the higher values of face angle, and was of such an order of magnitude as to be considered almost negligible as compared with the effect of face angle.

The percent separation varied with blowdown, Figure 23, in essentially the same manner as shown by Harwell.[16] It was noted, however, that the percent separation ran considerably higher in the new apparatus. This may be due to the enlarged section at the entrance of the clean air duct, as was predicted and recommended in Harwell's thesis.[17]

The efficiency, as defined in this thesis, decreased with increasing blowdown percent for all values of face angle except 45 degrees. The results for the 45-degree face angles are not too conclusive, as it was necessary to eliminate five of the eleven blades at this angle in order to hold entrance cross-section constant. The curves, Figure 24, were plotted by the method of least squares, since straight lines seemed to best fit the data. The form of these results is interesting, but as yet unexplained.

There was a slight trend toward increasing efficiency with increased initial air velocity, see Figure 25. Here, as with Harwell, the range was limited by the capacity of the blower. The trend indicated

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[16] *Ibid.*, p. 28.

[17] *Ibid.*, p. 18.

was slight, and the data scattered somewhat, so the results are not conclusive.

Accuracy

The dust input was measured by taking the weight of the dust feed cylinder before and after each run, and the dust separated and the dust in the clean air were measured by weighing the dust collecting bags before and after each run. This provided a check on the accuracy of measurement, and of collection. The difference in the weight of dust collected and the dust input (see Table I) was usually less than one percent of the dust input (and never exceeded one and one-half percent). In calculations of dust flow, and initial concentrations, the weight of dust collected was used as total dust rather than the dust input as measured by weighing the dust cylinder. This was to prevent attributing the unaccounted for dust to inefficiency of the separator.

The air flow meters also offered a check on the accuracy of measurement, since an orifice was used to meter total, or initial, air flow, and orifices were located in both air streams beyond the separator. The blowdown air flow, w_2, as used in subsequent calculations was arrived at by subtracting the clean air flow from the total air flow. The flow indicated by the orifice in the blowdown stream, w_2^*, served as a check on the instrumentation and calibration, see Table III. The calibration of air meters is to be found in Appendix D.

It is estimated that the total experimental error in measurement was not in excess of four percent of the magnitude of the data. There were probably some errors in reproducing the exact geometry of the separator for all the runs; the error introduced in this manner can hardly be estimated.

VII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

If one considers the actual mechanism of separation in the light of the results for optimum value of face angle obtained in this study, an interesting conclusion may be drawn. It was shown that for the two dimensional separator the maximum separation occurred when the angle of the louvre face was set at a value of 15 to 22-1/2 degrees. If the separation is actually influenced by the angle at which the dust or the air strikes the louvres then this optimum angle should be the same for a three dimensional, or conical shaped, separator. This does not appear to be the case. The angle determined for conical filter elements is specified in the range three to ten degrees.[18] A cone whose cross-section for flow varies with distance approximately as the variation of cross-section in an optimum two dimensional design would have a face angle in the range three to ten degrees.

It can be shown that the cone whose variation of circular cross-section with distance (height) is most nearly equal to the variation of cross-section with distance of a right prism is the cone having twice the height of the prism, the base area of cone and prism being equal; see Appendix C. If the entrance cross-section (base) of the cone is to be the same as that of the prism then the radius of the base of the cone is $R = \sqrt{A/\pi}$. The entrance cross-section of the two dimensional separator was 2 inches by 3 inches, or 6 square inches, therefore the radius of the base of a cone of equal area is 1.38 inches. The height of the prism was $h = 3/\tan 18^\circ = 9.24$ inches, and the height of the

[18] E. T. Linderoth, United States Patent No. 2,506,273, May 2, 1950.

optimum cone is 2xh, or 18.48 inches. The face angle of the conical filter surface is then arctan 1.38/18.5 = arctan 0.0746 = 4.3 degrees.

This seems to indicate that the important factor is the cross-section available for flow in the direction of blowdown air rather than the angle of the filter surface.

It is disturbing that the initial air velocity had no more effect on the separation than that indicated, even though the results are in accord with those obtained by Harwell. Zverev[19] has found this to be an important factor, as has Linderoth.[20] It is necessary to consider these results as inconclusive, perhaps because of the limited range of variation of velocity.

Although the percent separation increases as the percent blowdown air is increased, the separation does not increase in the same proportion, at least in the practical range. For this reason, the efficiency, which includes the ratio of clean air to initial air, decreases with increasing blowdown. This would indicate the advisability of operating a louvre dust separator at low blowdown rates, which is a desirable situation, requiring a smaller blower and less power to recirculate the blowdown air.

Recommendations

Only a few of the variables thought to affect the performance of

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[19] N. E. Zverev, "Shutter Type Dust Collector of Small Dimensions," The Engineers Digest (American Edition), Vol. 3, No. 11, November 1946, pp. 557-59. (From Isvetya Vsesoyuznogo Teplotechnicheskoga Instituta, Vol. 15, No. 3, 1946, pp. 12-15.)

[20] Linderoth, loc. cit.

louvre type dust separators have been investigated, and the results of some of these are not conclusive. The apparatus, in its present design, has not exhausted its usefulness, and it is hoped that it will be utilized for further study of the problem.

If any subsequent study is performed at the Georgia Institute of Technology it is recommended that a new dust feeding apparatus and a larger blower are in order. It would be desirable to increase the dust load sufficiently to examine the effect of varying concentration. Also a blower of about 400 cfm. capacity would be desirable to extend the range of initial velocities.

One of the more interesting variables, and perhaps the most important, is the nature of the dust used. In this study the dust consisted of crystals of aluminum oxide of specific gravity 4, with an average particle size of 70 microns (the same as used by Harwell). An entire thesis could be submitted on the effects of dusts of various densities, specific surface, size, settling velocity, and so forth.

All of the variables of geometry have not been studied. The effects of blade spacing as well as blade shape are yet to receive attention.

The separator described in this thesis was designed with transparent cover plates for the purpose of obtaining visual evidence of the nature of the separation. This has not been attempted yet, but it is believed that the techniques of high speed motion picture photography, and high speed "strobe-flash" photography, are admirably suited to a study of this type, although, in the case of this investigator, prohibitively expensive.

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Linderoth, E. T., U. S. Patent No. 2,506,273, May 2, 1950.

Rhodes, T. J., Industrial Instruments for Measurement and Control. New York: McGraw-Hill Book Company, Inc., 1941. 573 pp.

Zverev, N. I., "Shutter Type Dust Collector of Small Dimensions," The Engineers Digest (American Edition), Vol. 3, No. 11, November, 1946. Pp. 557-559. (From Isvetya Vsesoyuznogo Teplotechnicheskoga Instituta, Vol. 15, No. 3, 1946. Pp. 12-15.)

APPENDIX A

FIGURES

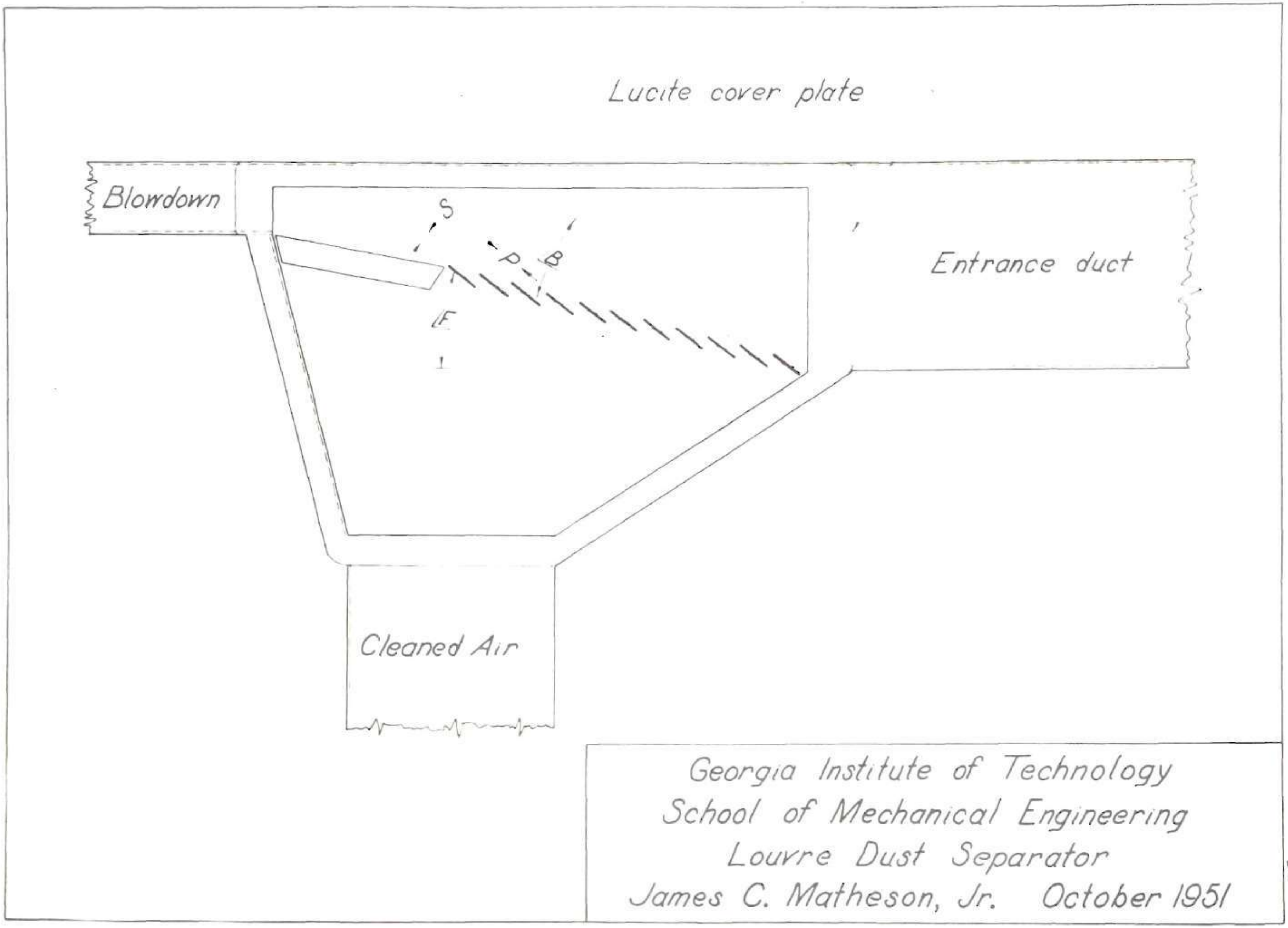

Lucite cover plate
Blowdown
Entrance duct
S
P
B
F
Cleaned Air
Georgia Institute of Technology
School of Mechanical Engineering
Louvre Dust Separator
James C. Matheson, Jr. October 1951

Figure 1

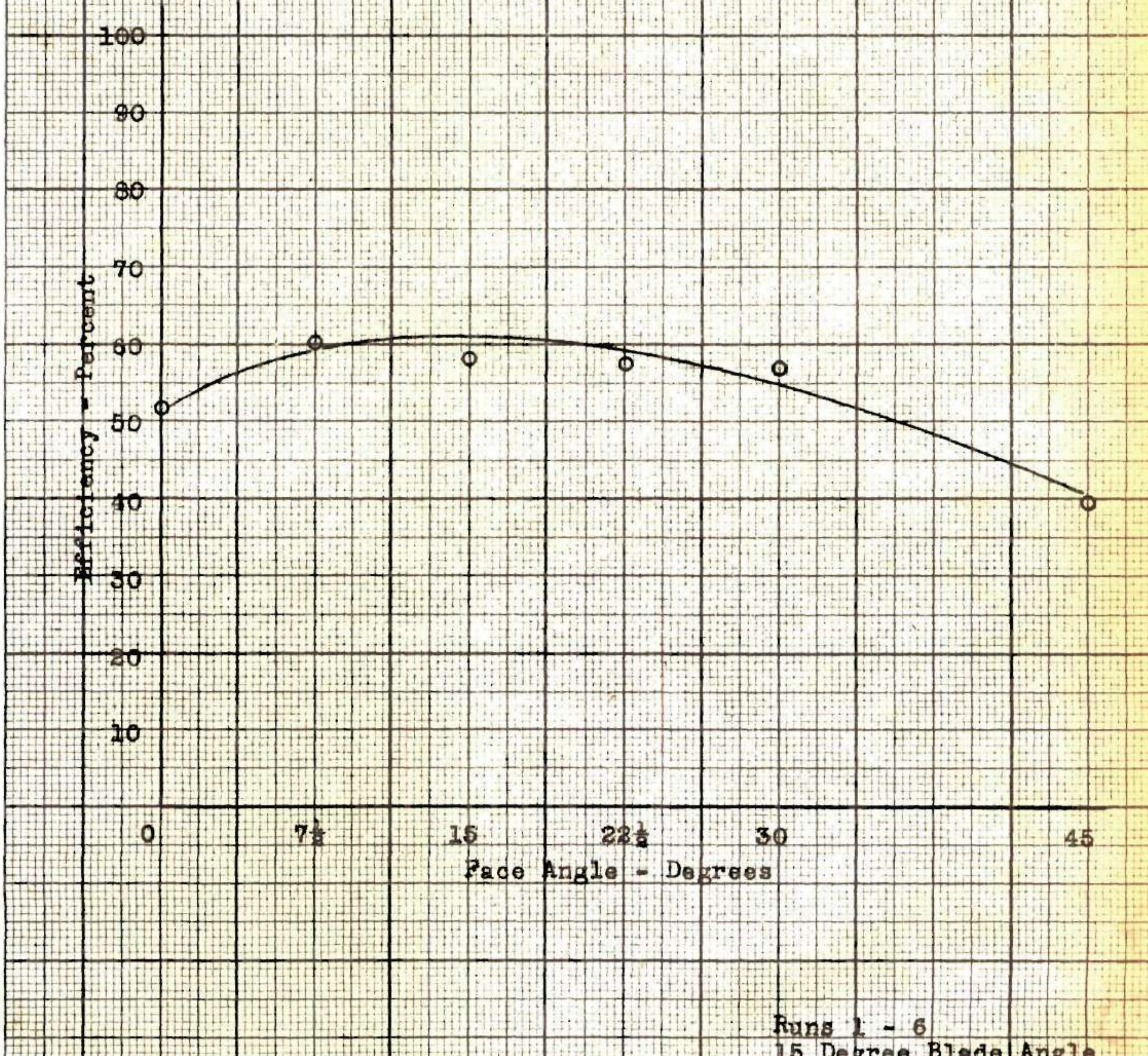
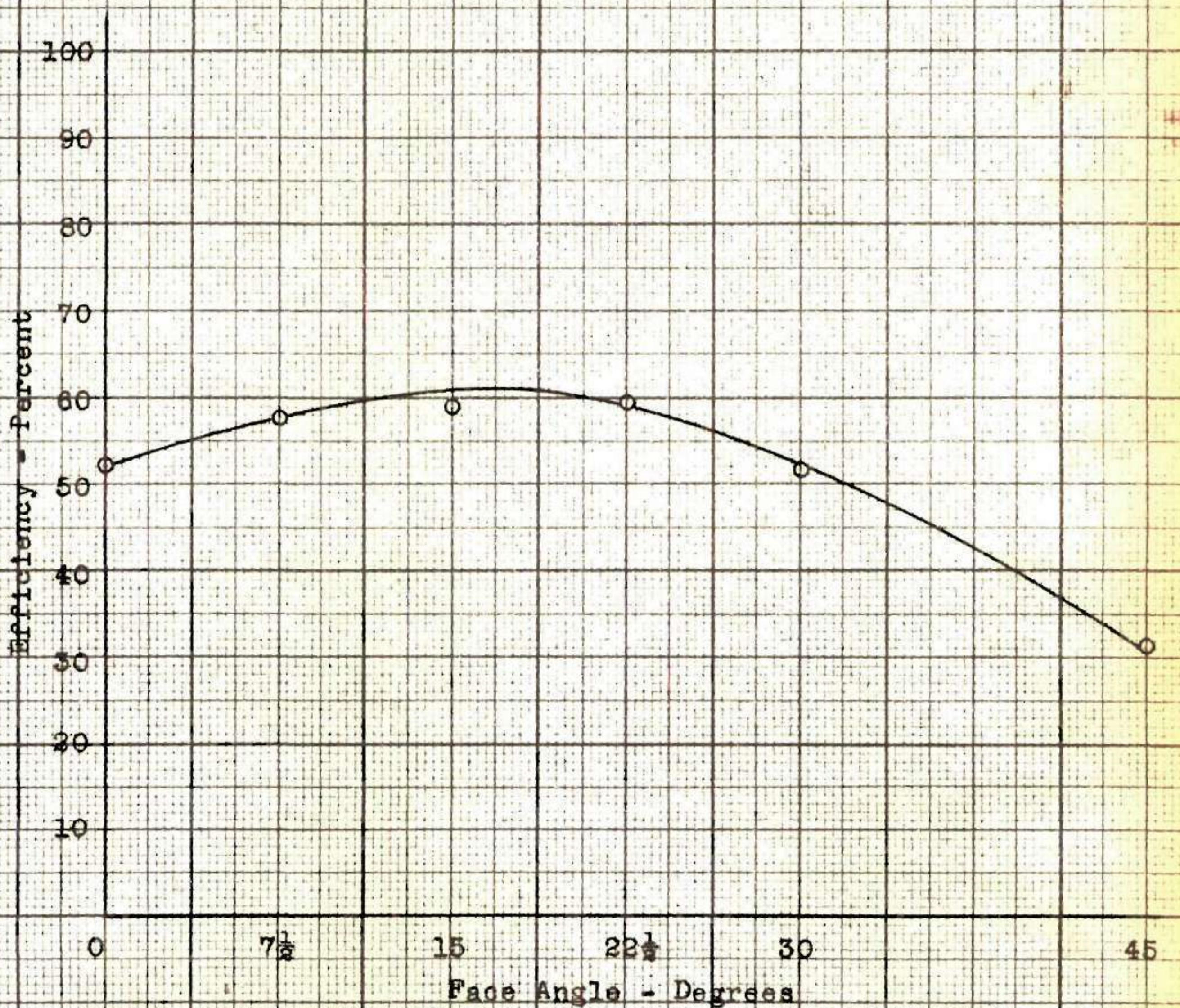


Figure 2

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951



Runs 7 - 12
22½ Degree Blade Angle

Figure 3

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

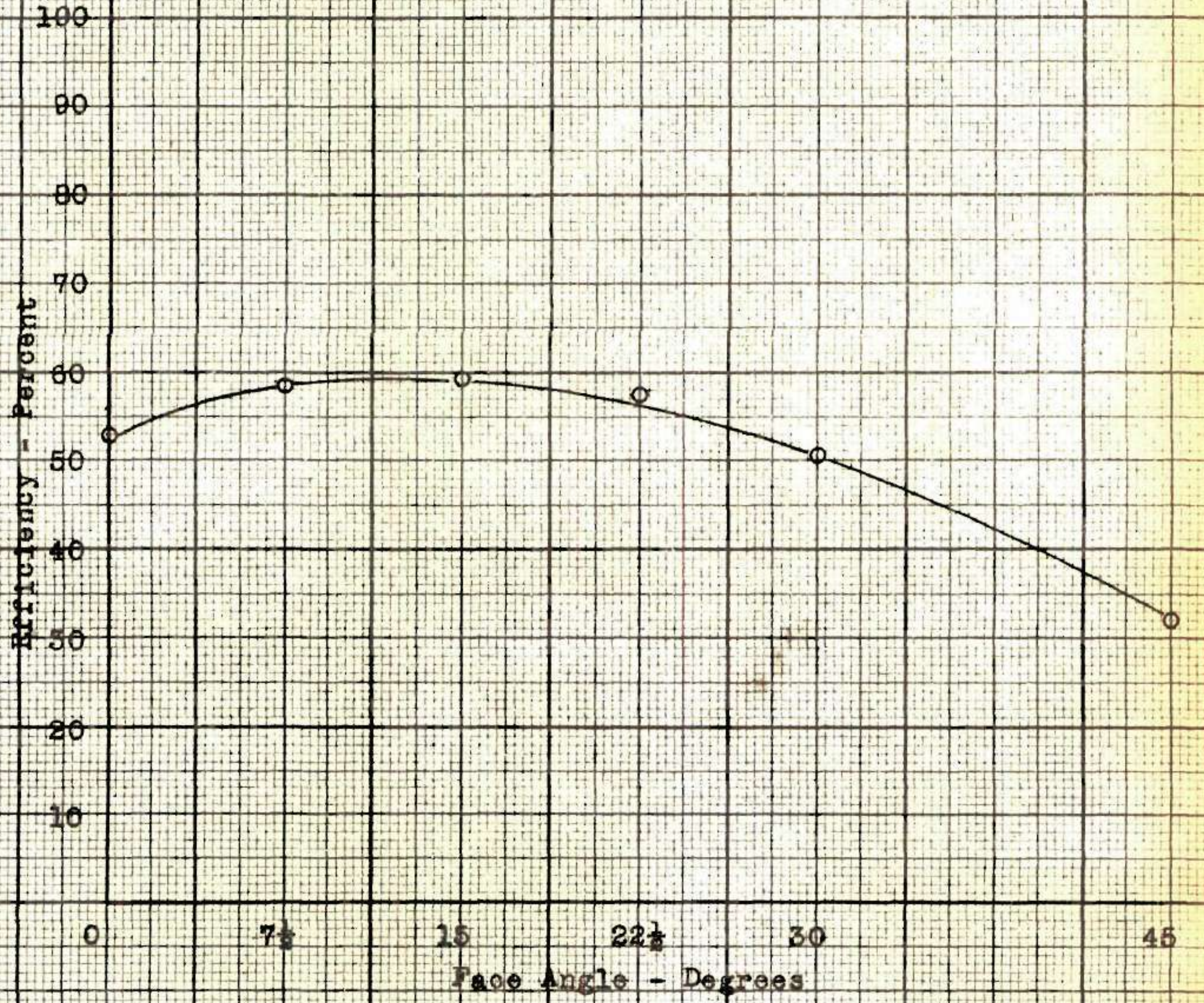


Figure 4

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

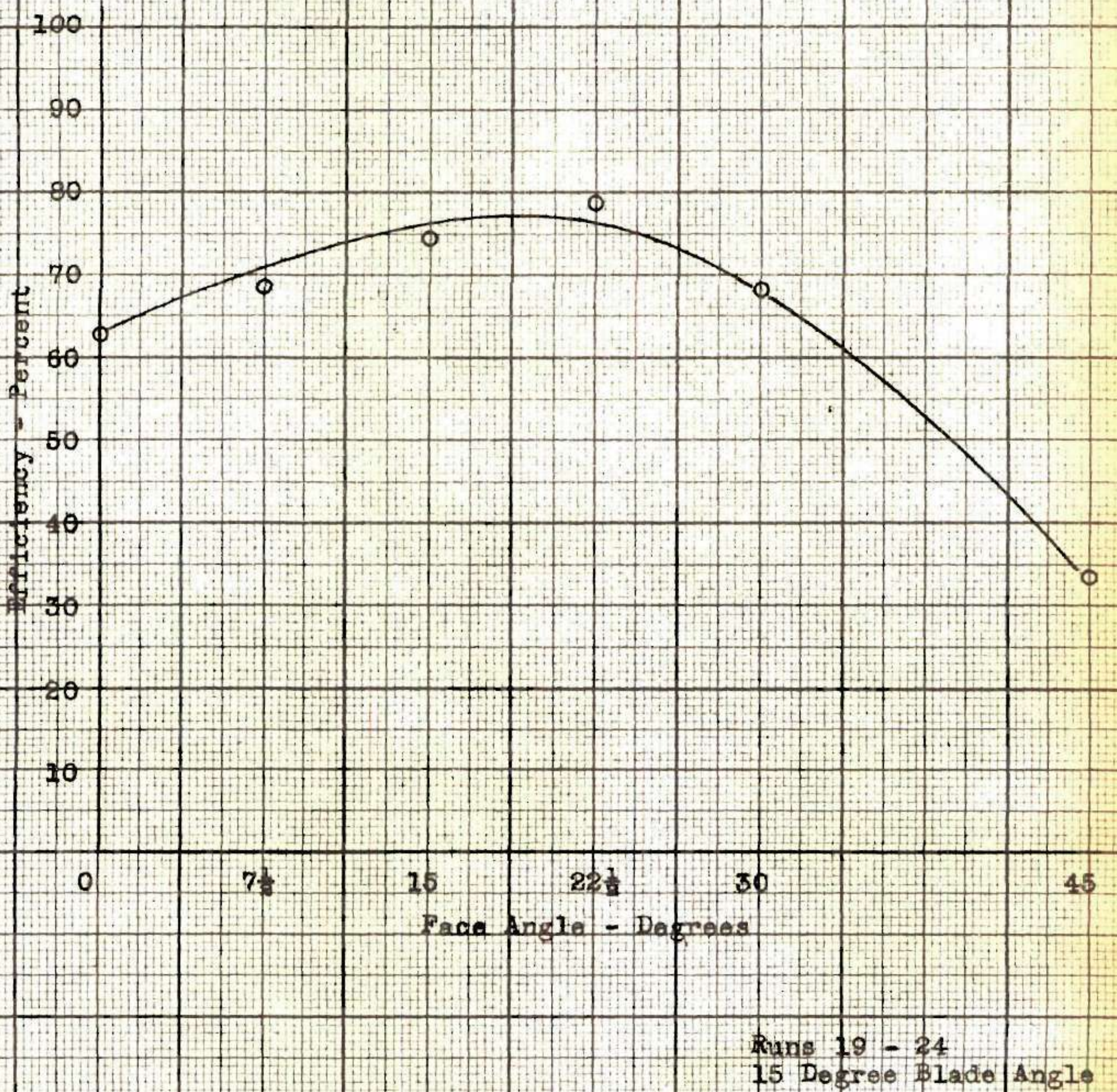


Figure 5

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr.   October 1951

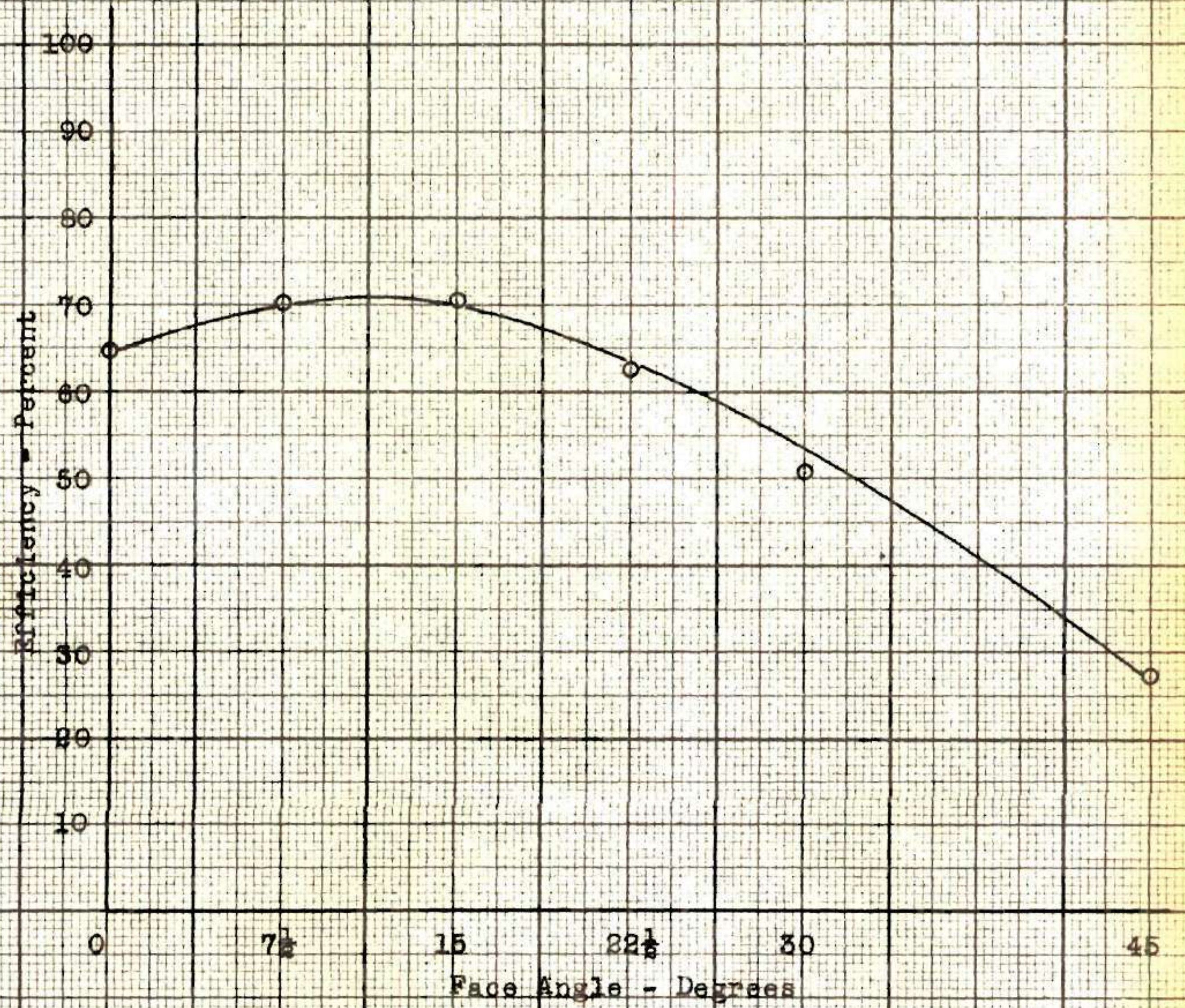


Figure 6

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr.   October 1951

FORM 5000   THE GEORGIA TECH CO-OP [illegible]

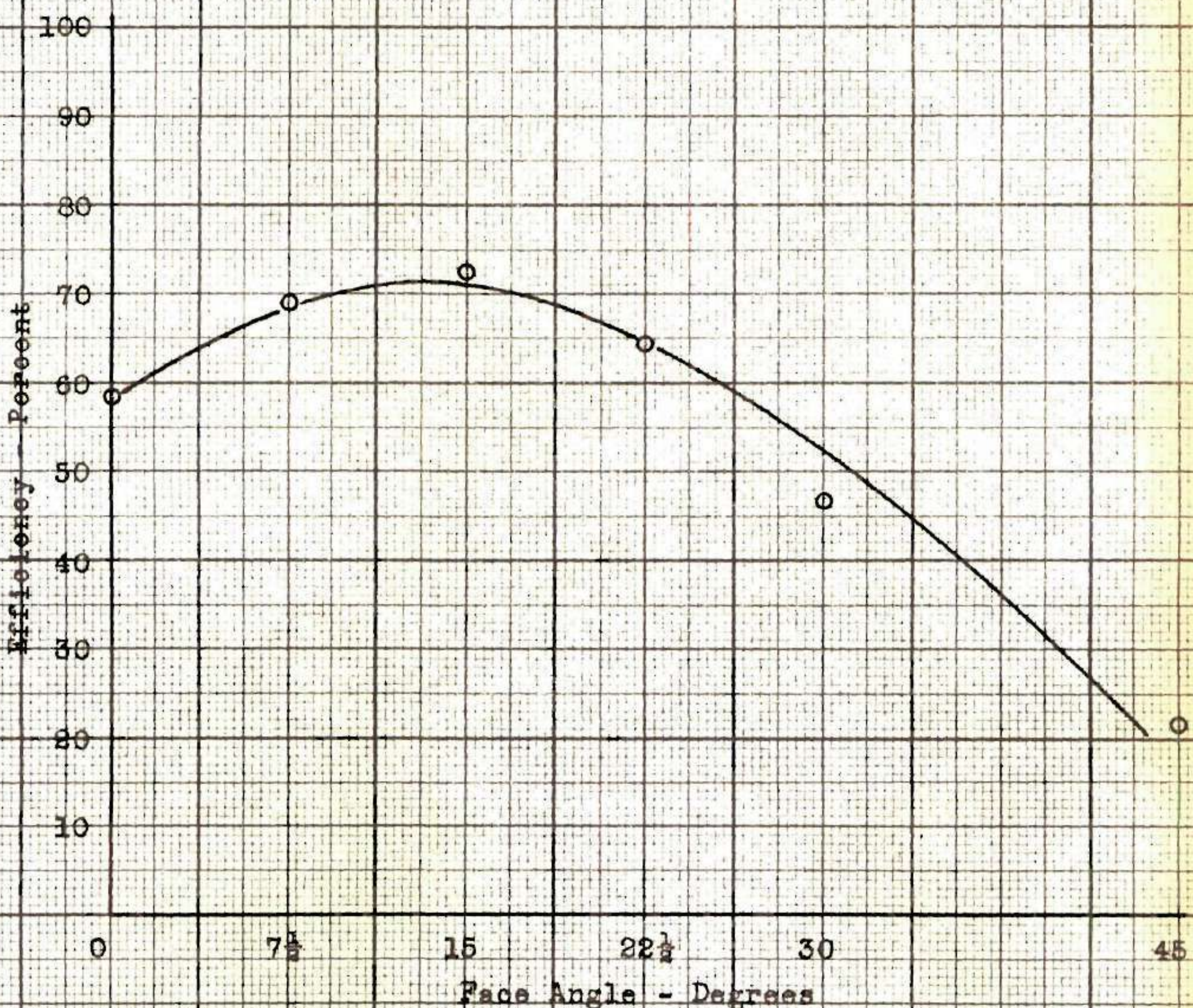


Figure 7

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

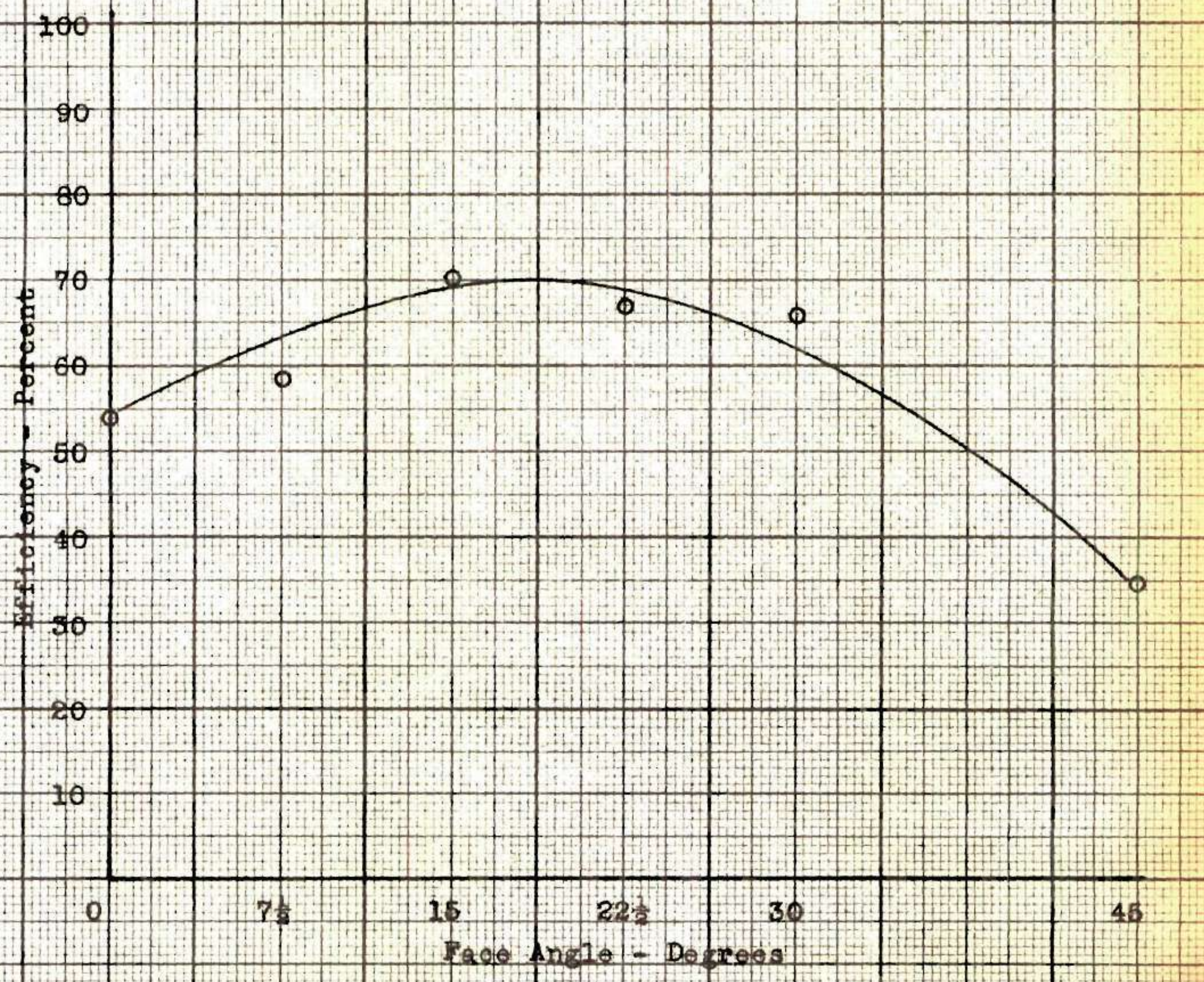


Figure 8

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James G. Matheson, Jr. October 1951

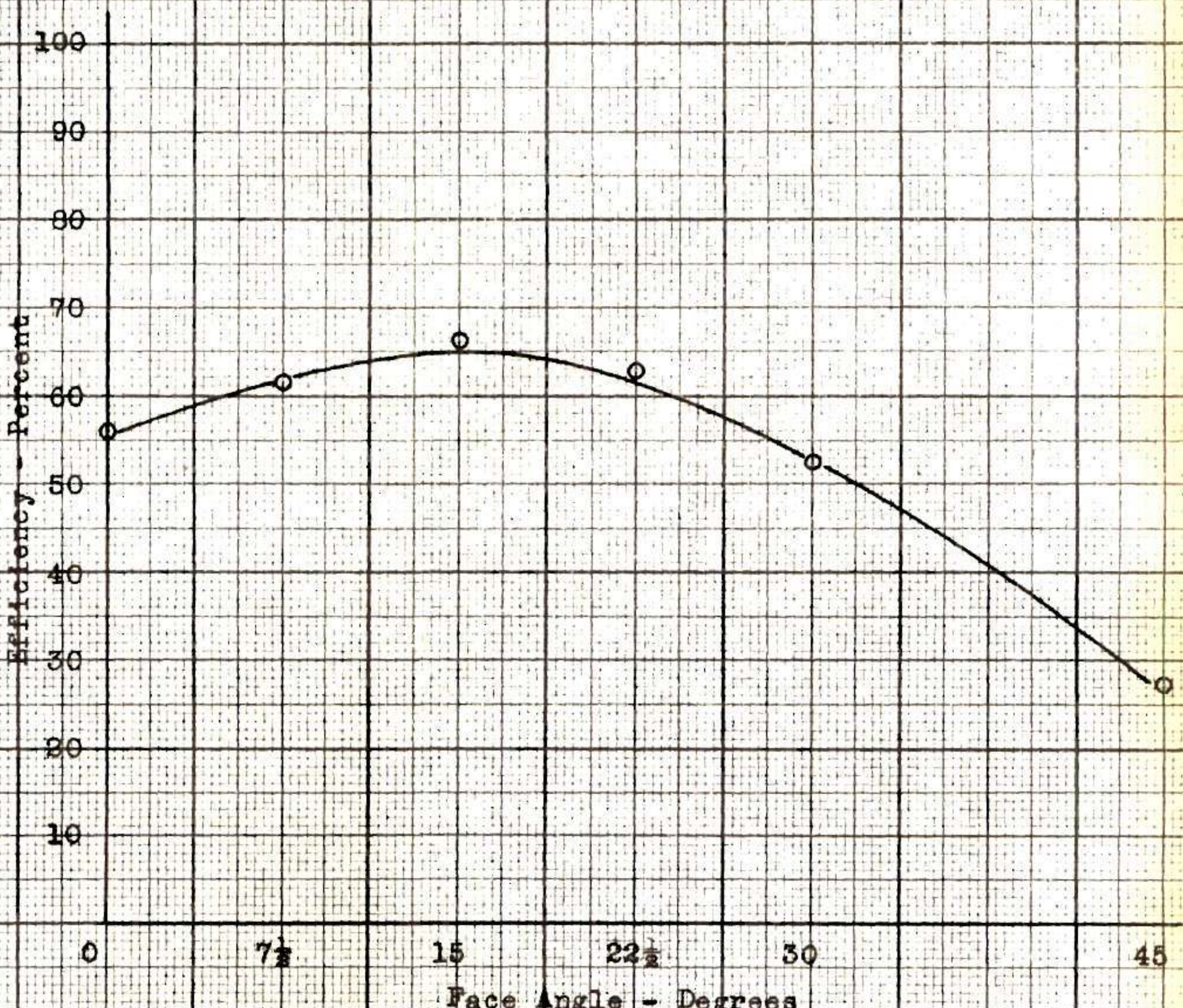


Figure 9

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

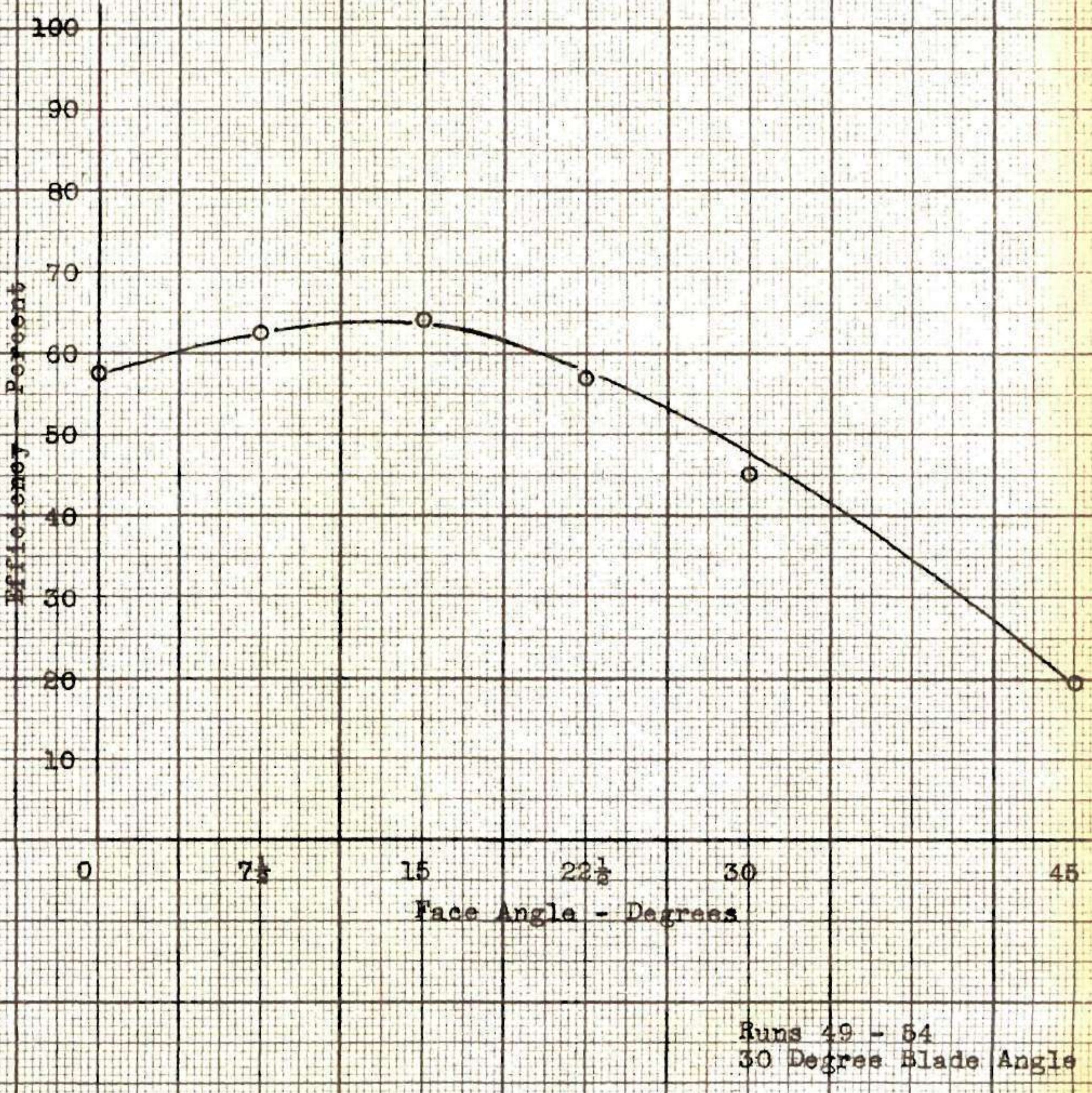
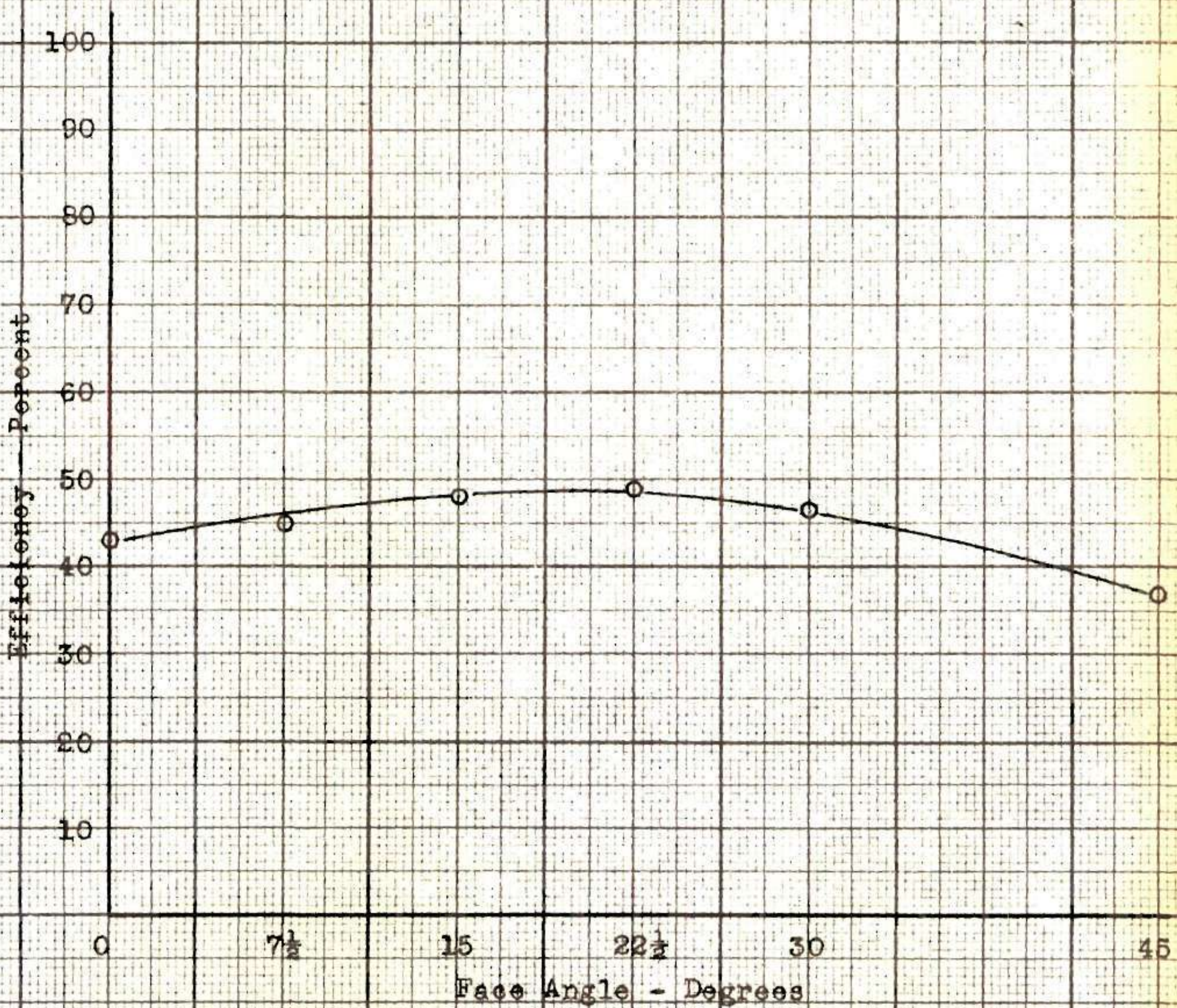


Figure 10

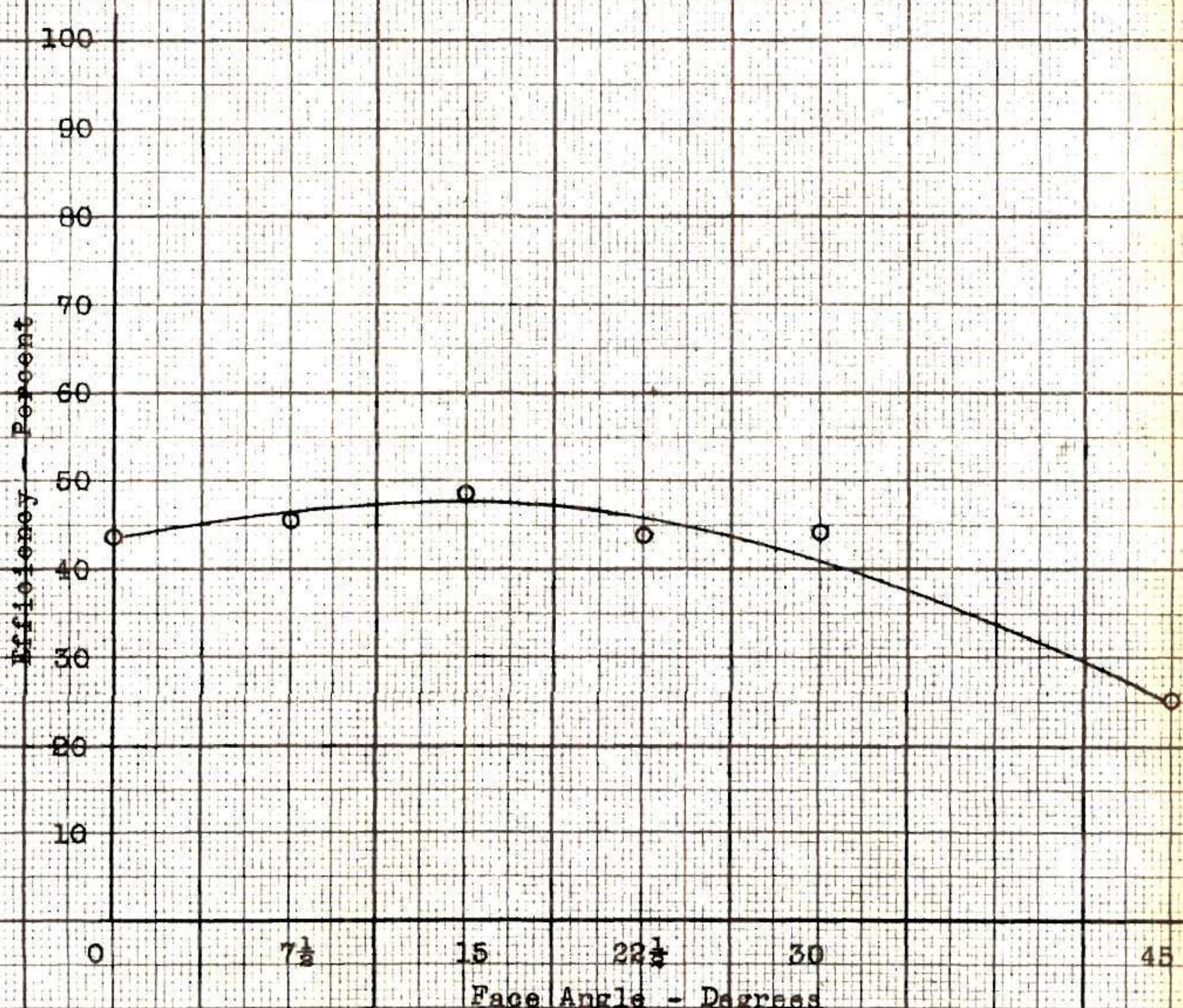
Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951



Runs 55 - 60
15 Degree Blade Angle

Figure 11

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951



Runs 61 - 66
22½ Degree Blade Angle

Figure 12

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

FORM 5000 THE GEORGIA TECH COLLEGE INN

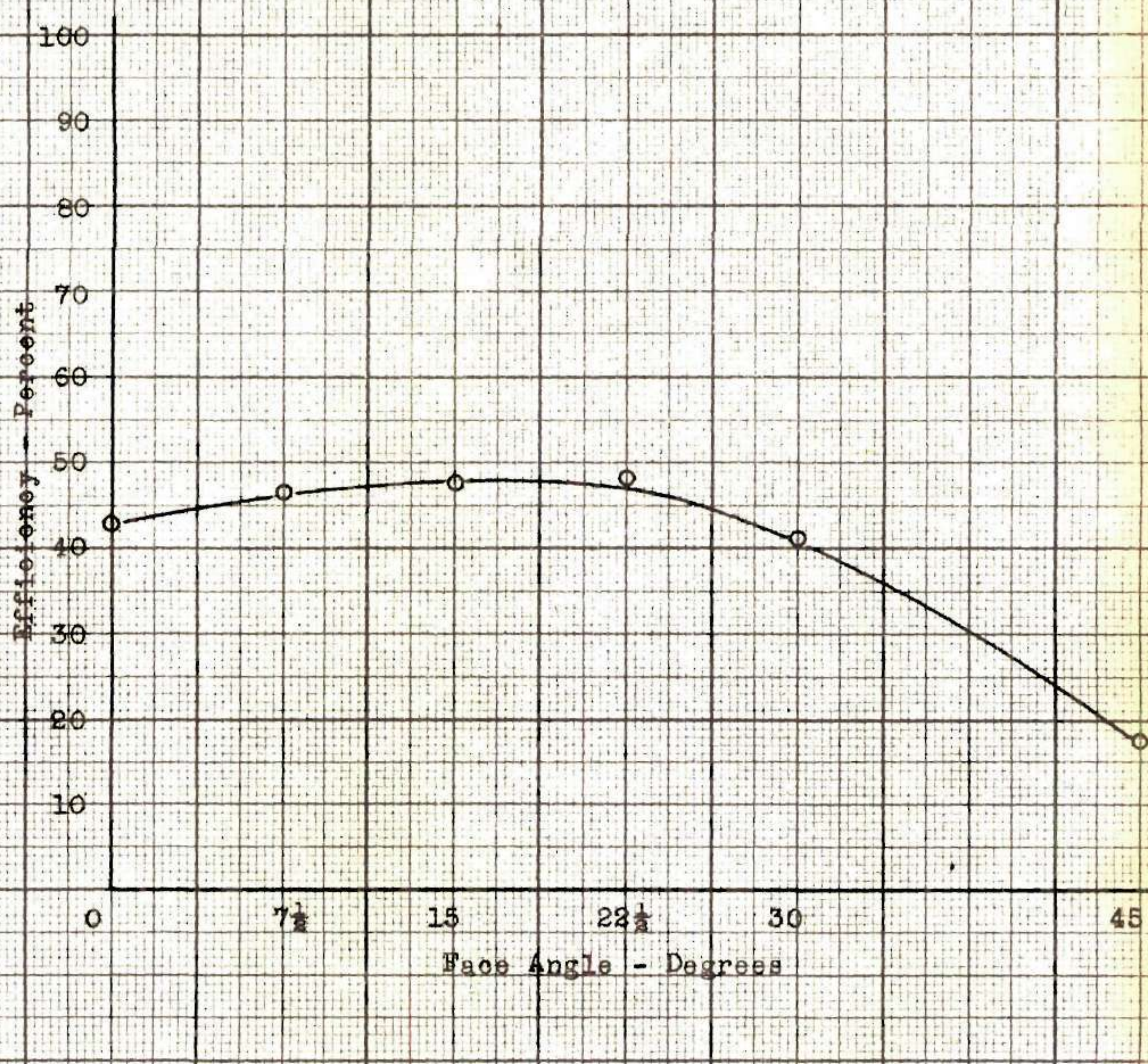
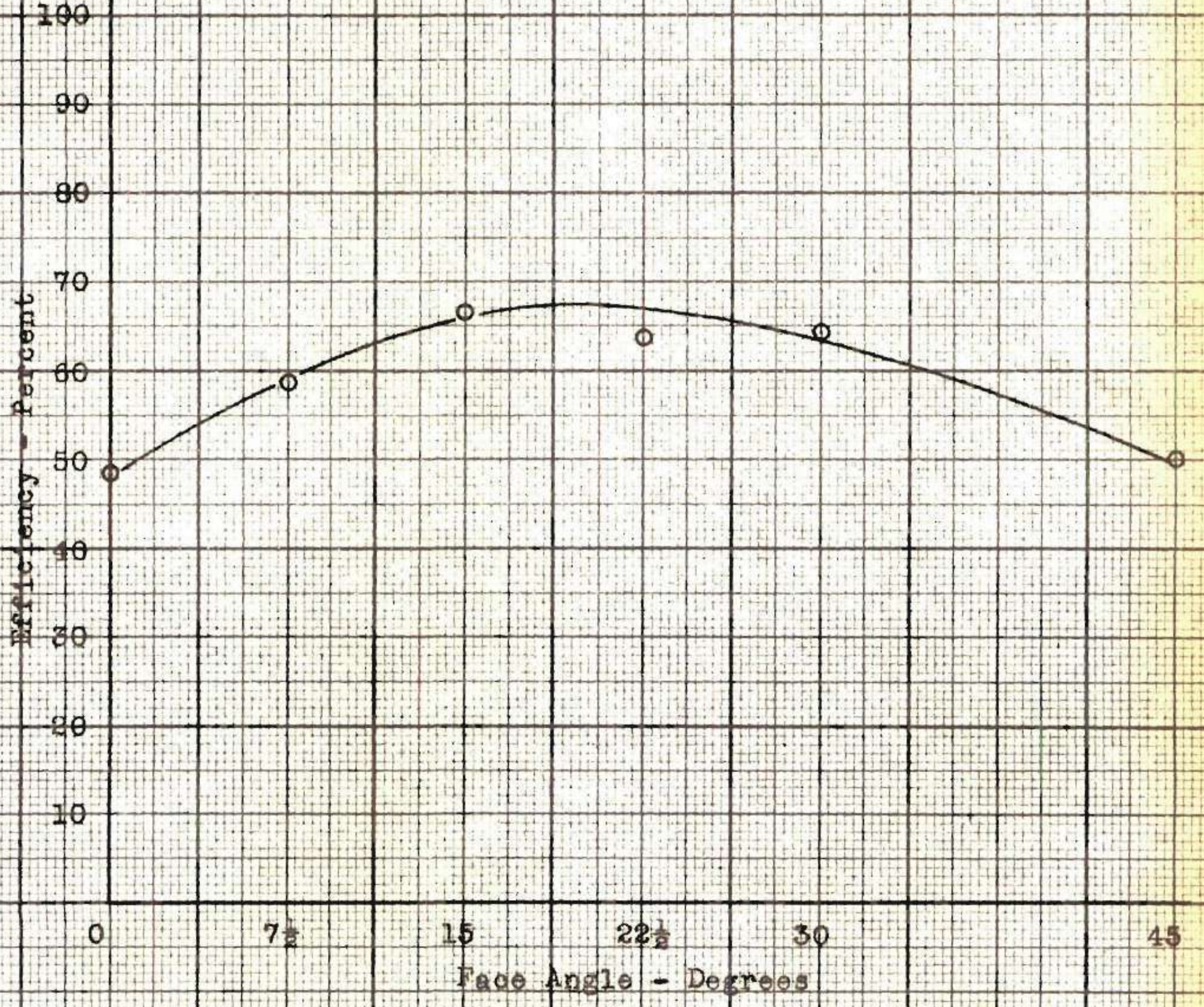


Figure 13

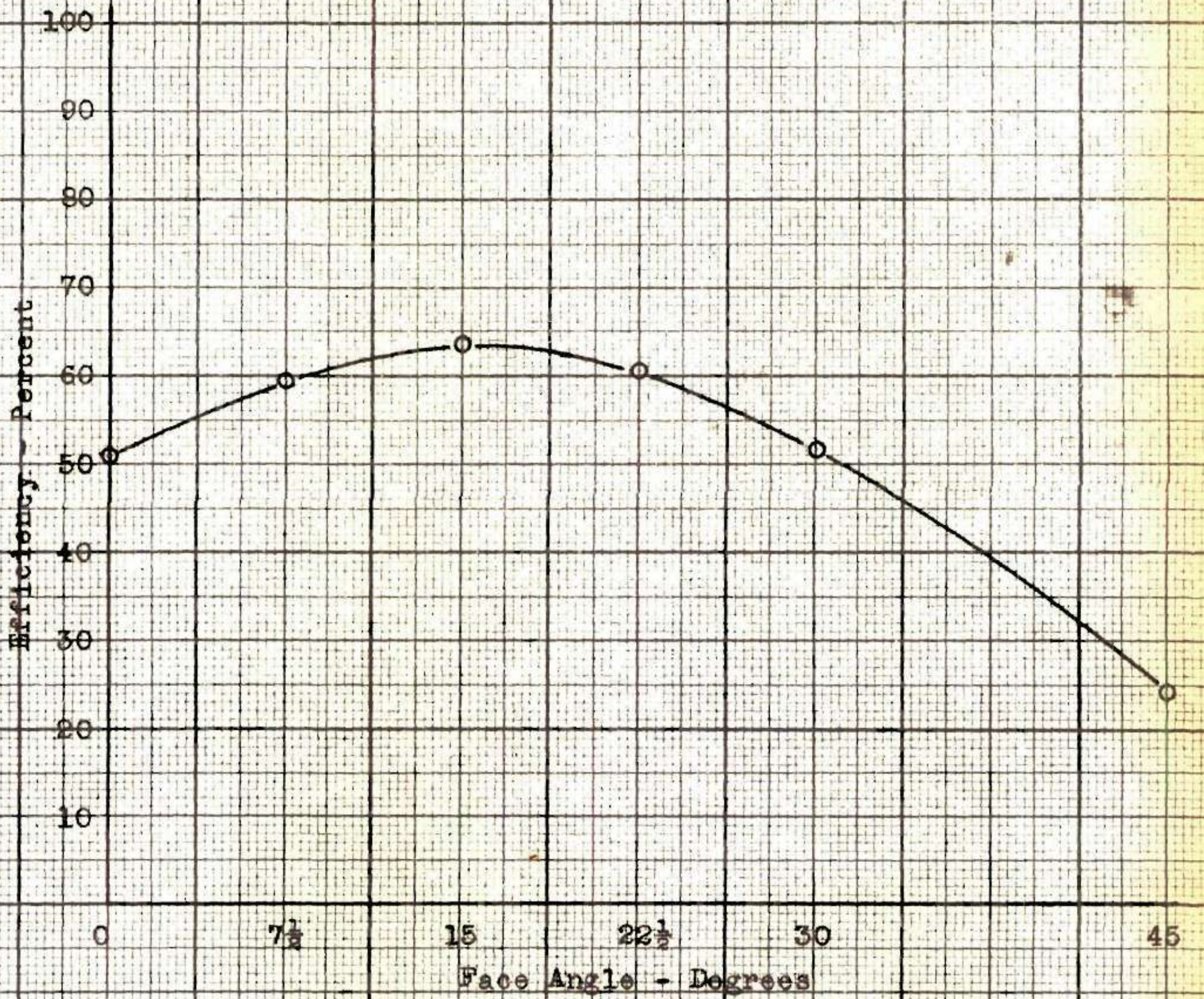
Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr.   October 1951



Runs 73 - 78
15 Degree Blade Angle

Figure 14

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James G. Matheson, Jr. October 1951

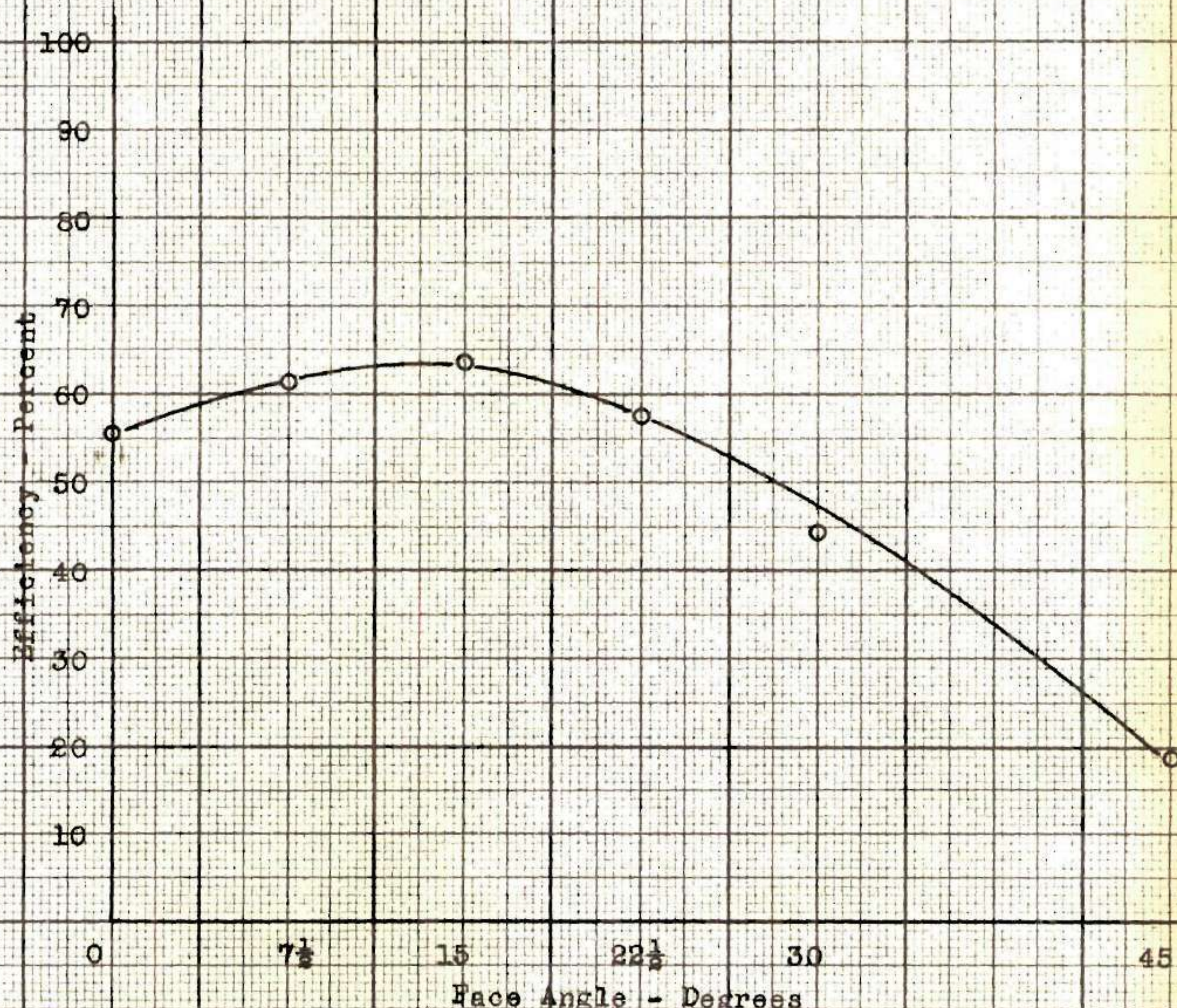


Runs 79 - 84
22½ Degree Blade Angle

Figure 15

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

FORM 5000 THE GEORGIA TECH COLLEGE INN



Runs 85 - 90
30 Degree Blade Angle

Figure 16

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James G. Matheson, Jr. October 1951

FORM 5000 THE GEORGIA TECH CO[illegible]

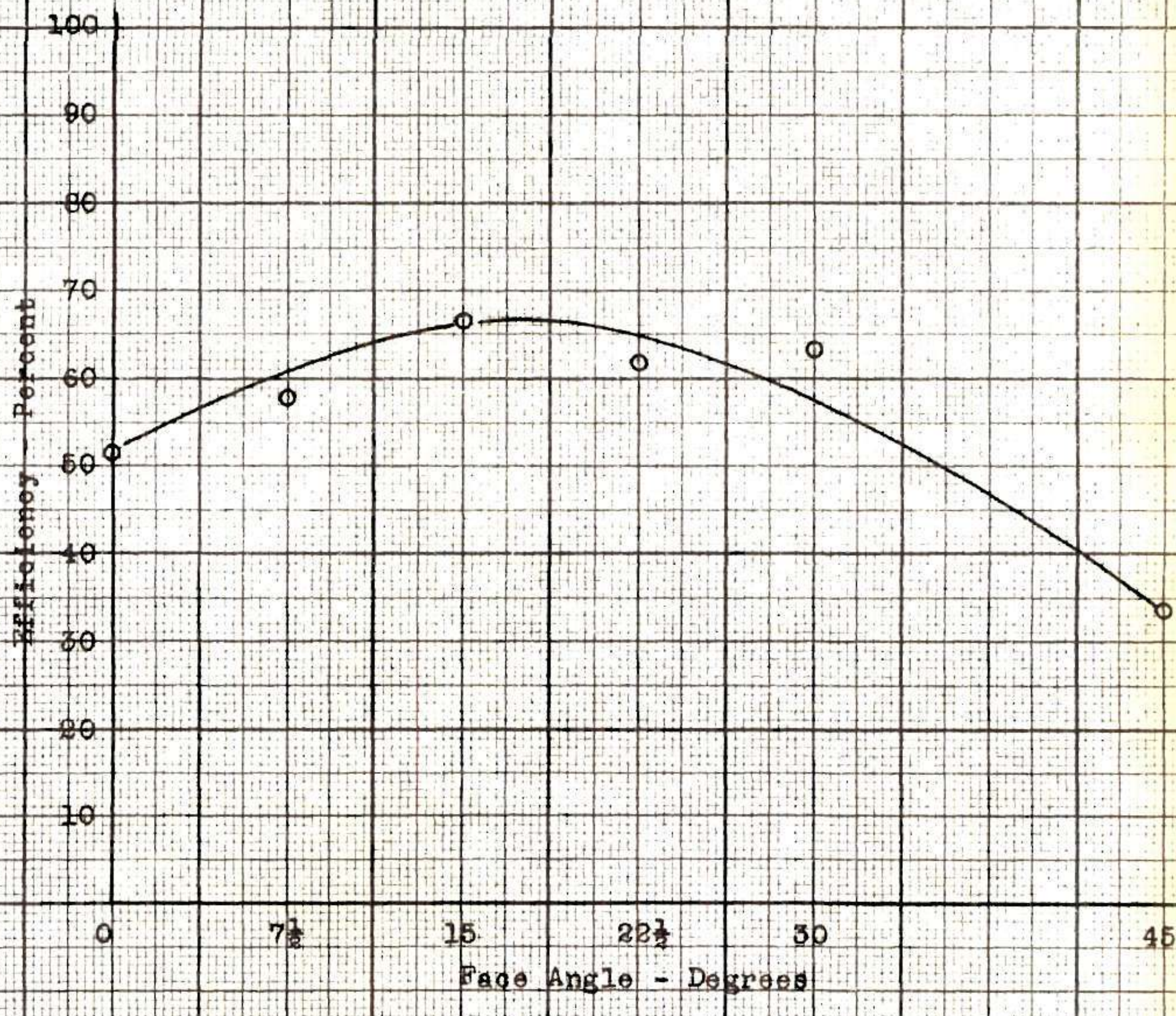


Figure 17

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

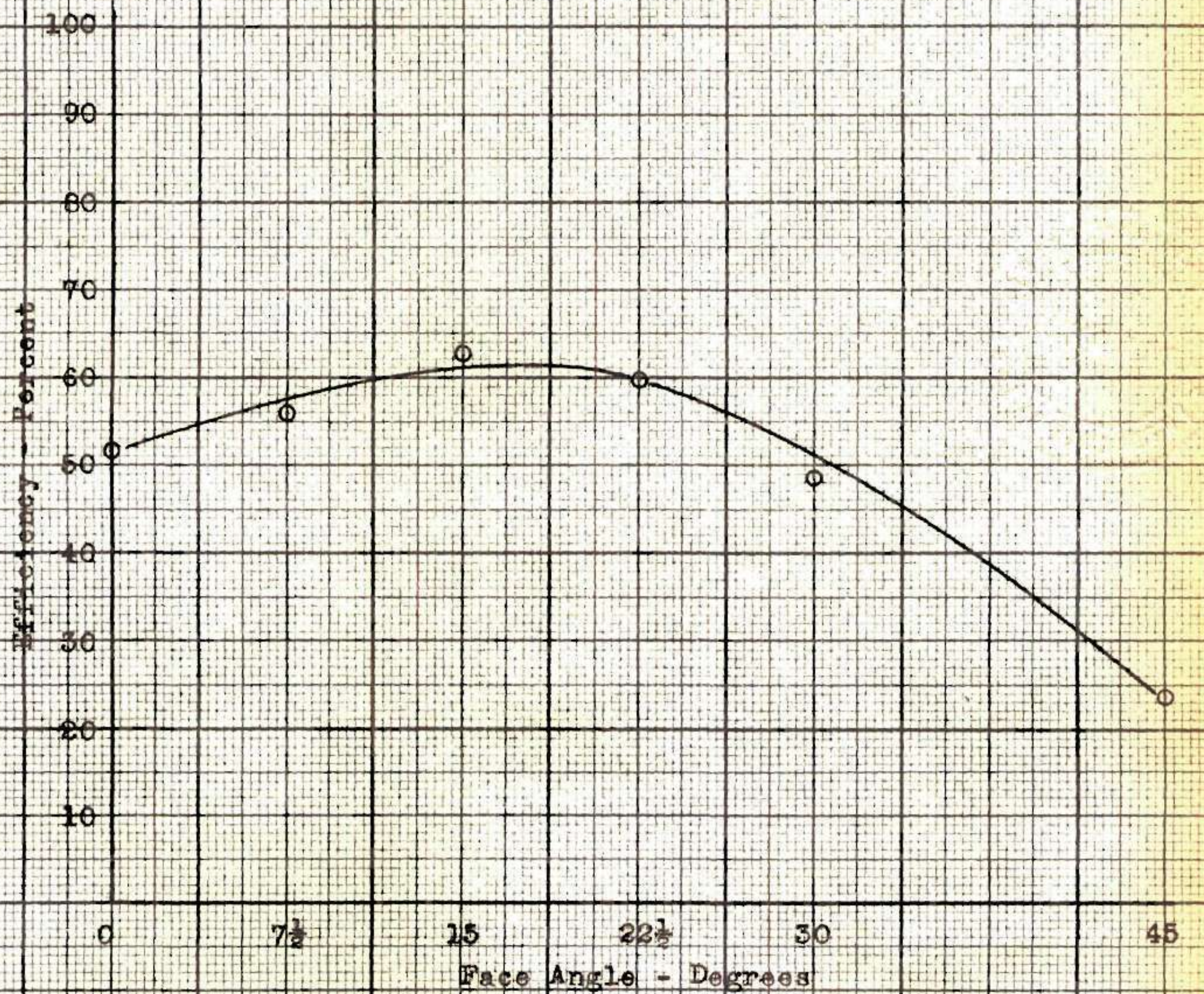


Figure 18

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

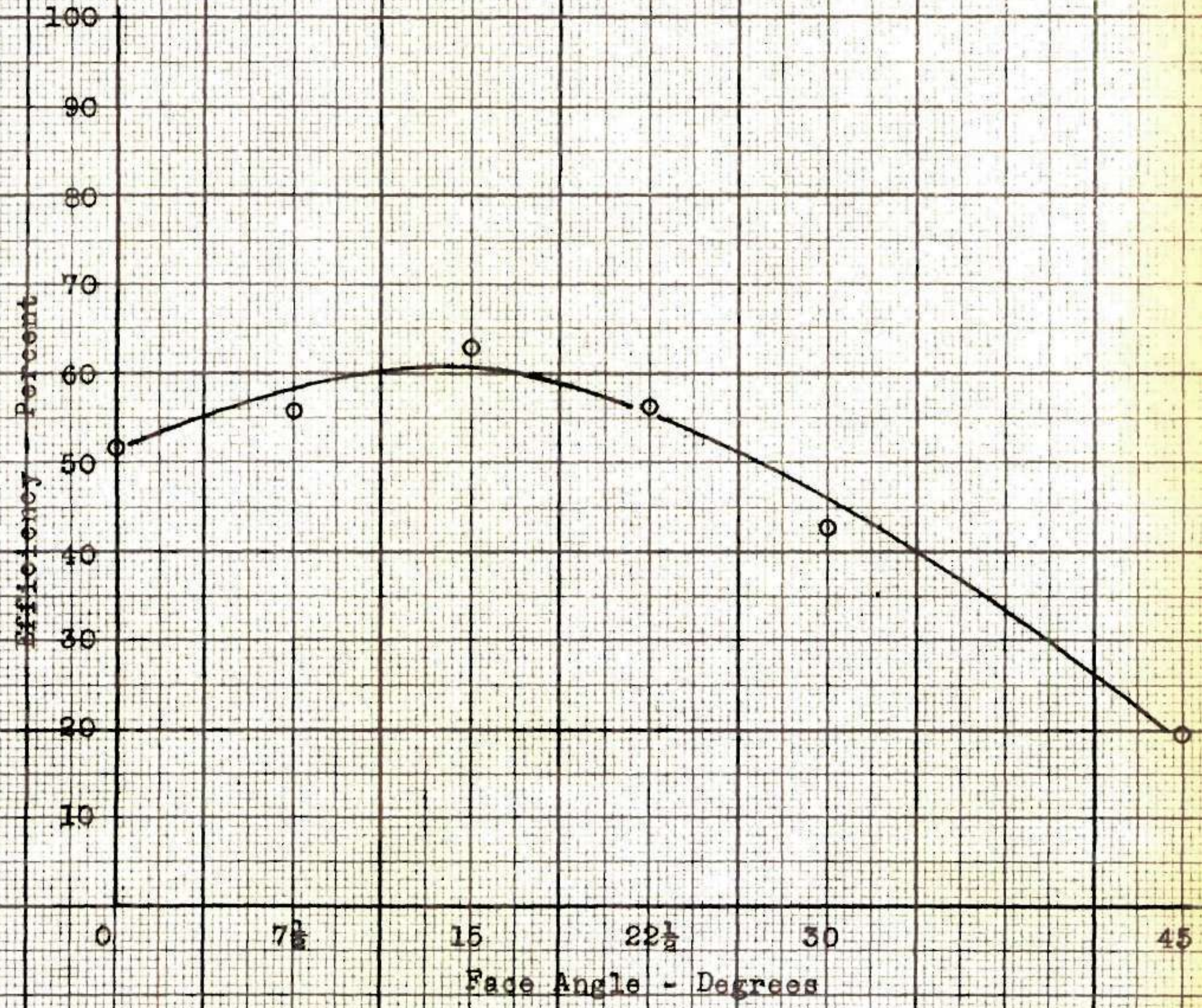


Figure 19

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr.   October 1951

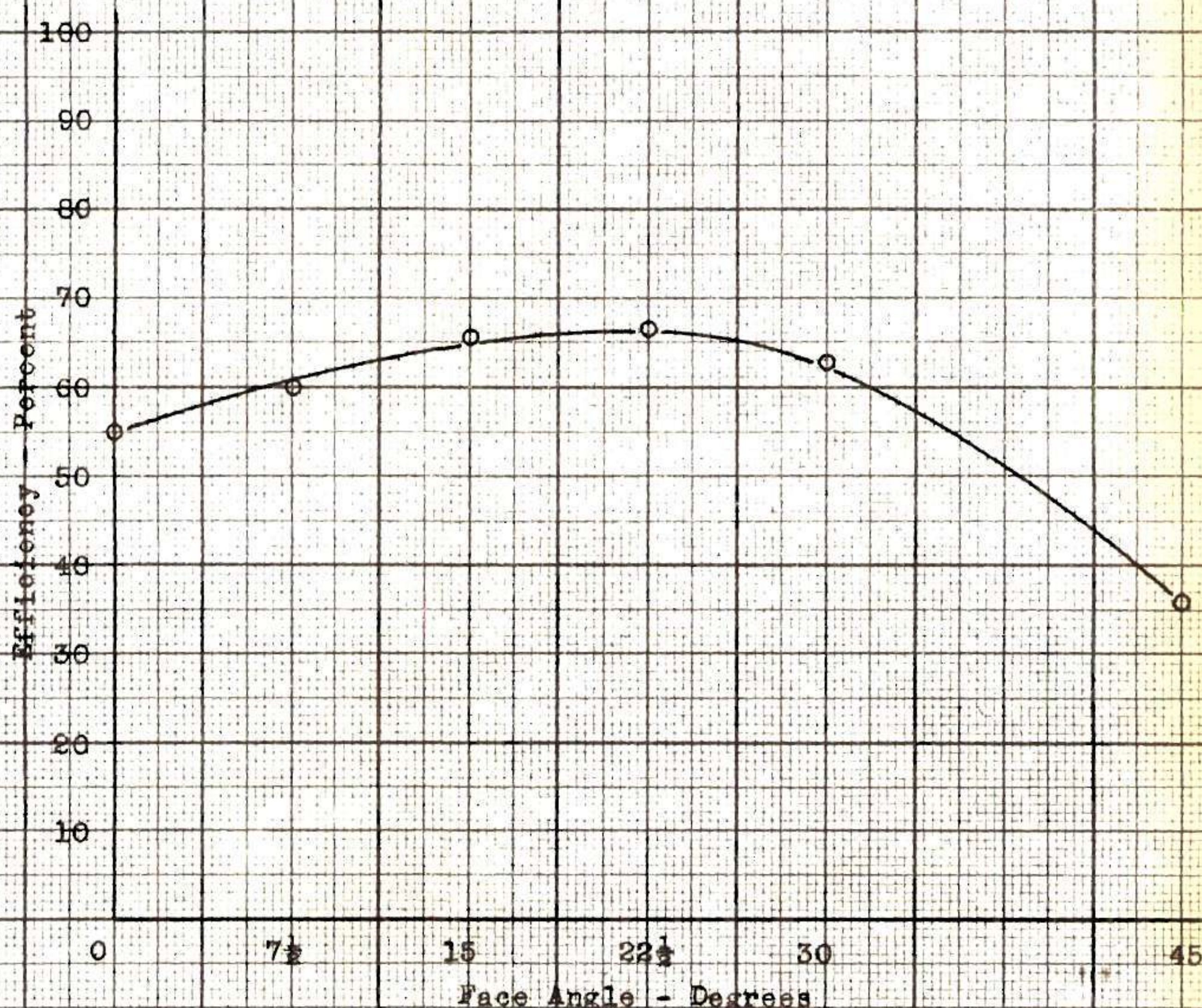


Figure 20

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

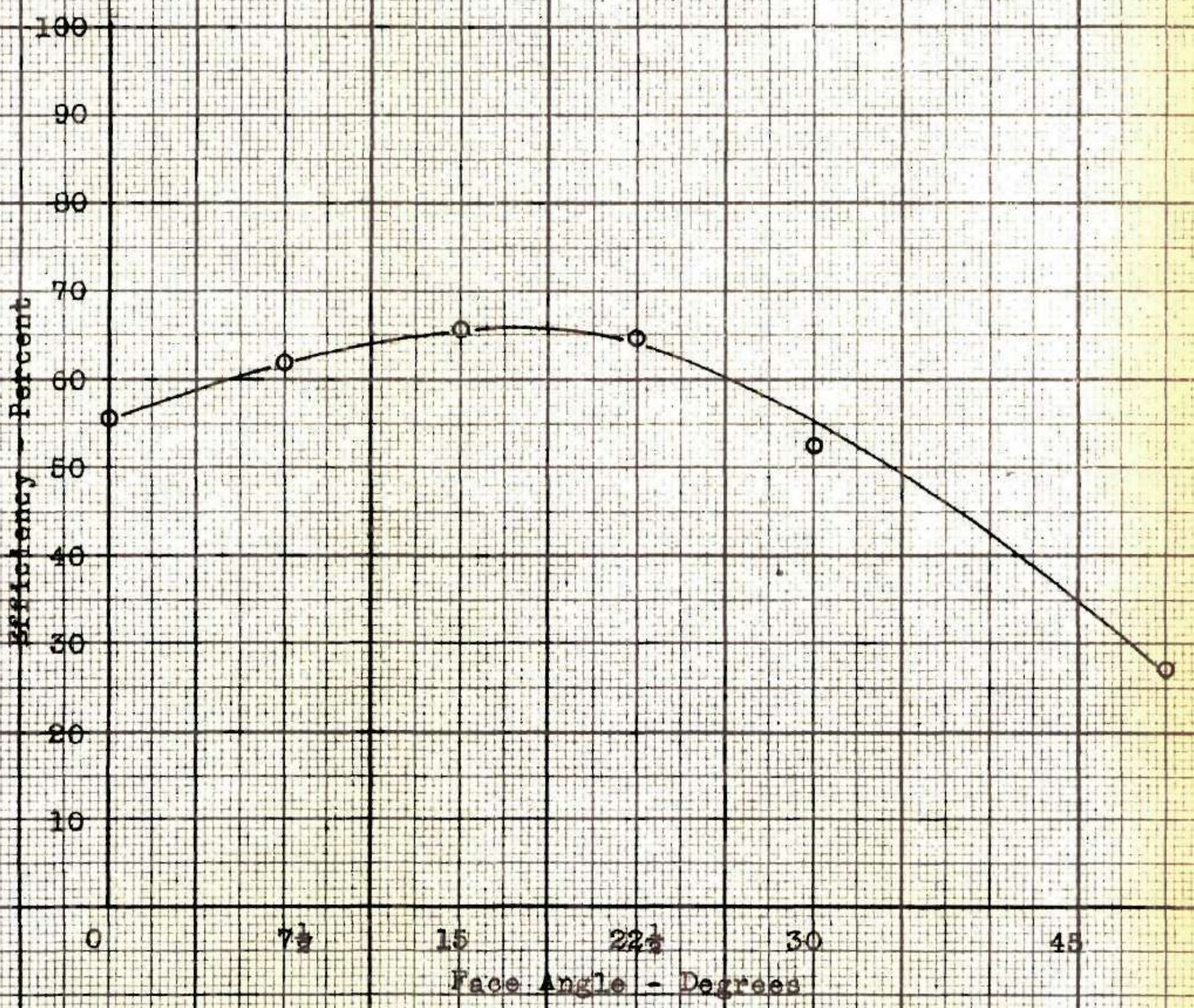


Figure 21

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951

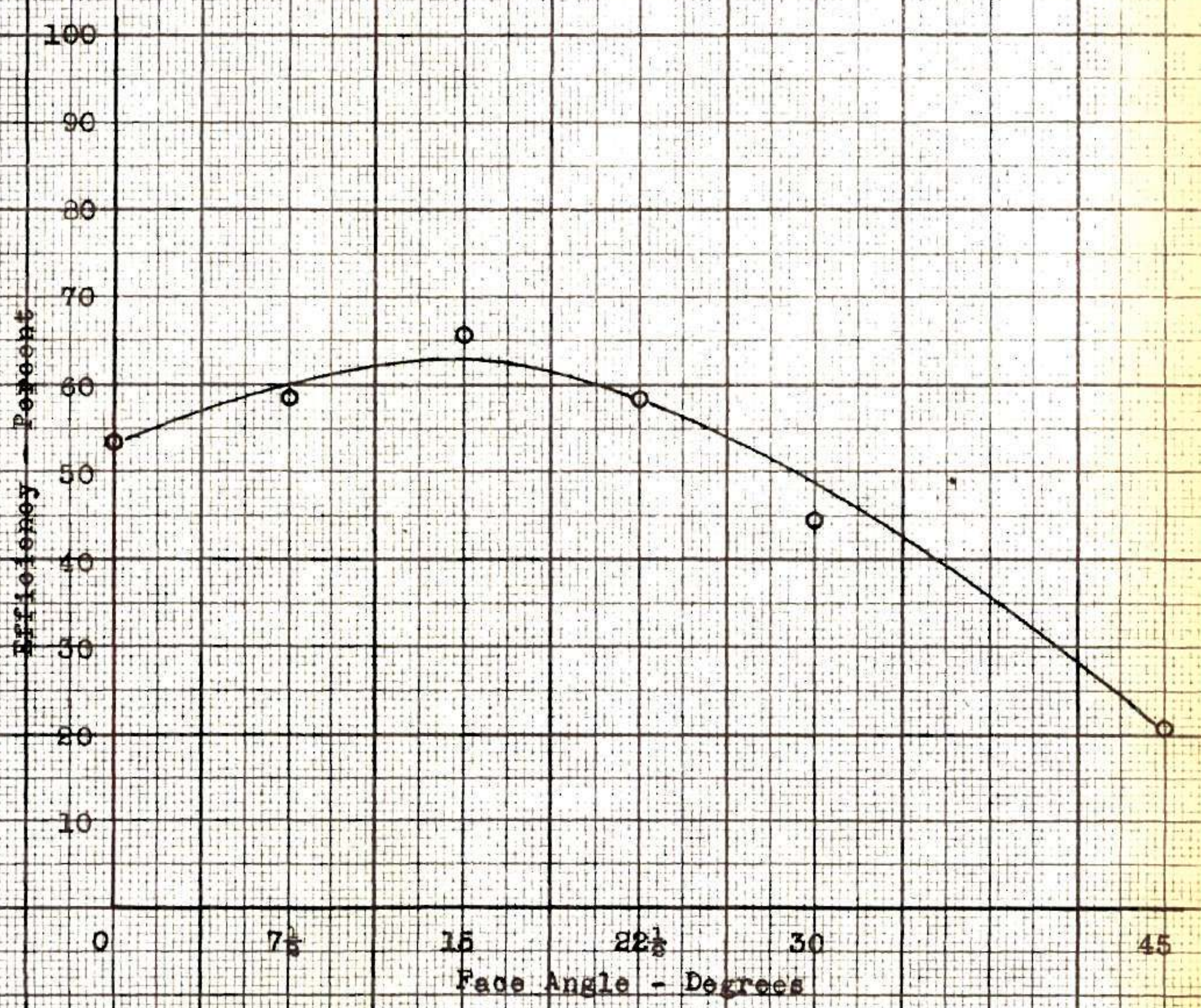
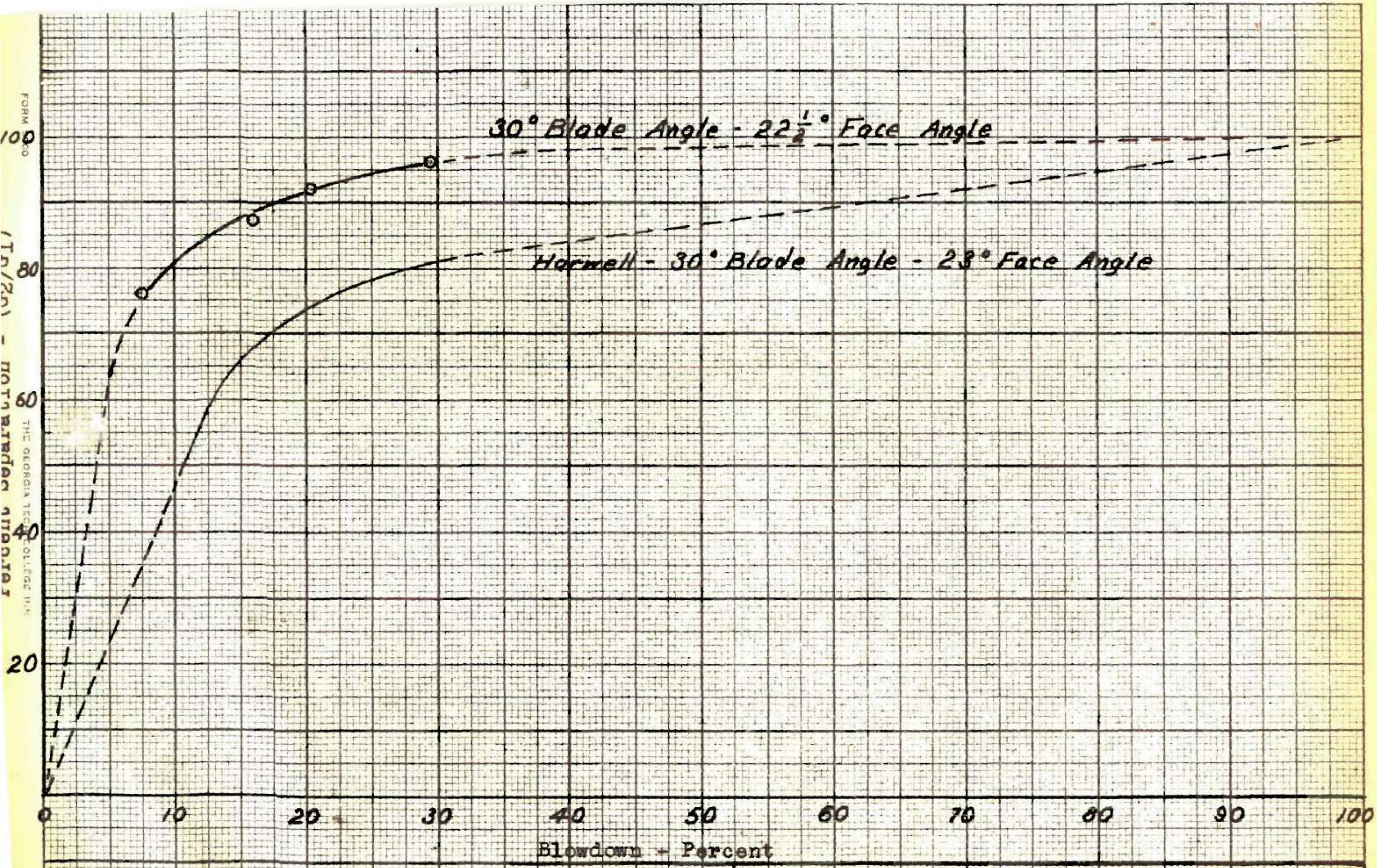


Figure 22

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus FACE ANGLE
James C. Matheson, Jr. October 1951



Georgia Institute of Technology
School of Mechanical Engineering
PERCENT SEPARATION versus BLOWDOWN
James C. Matheson, Jr. October 1951

Figure 23

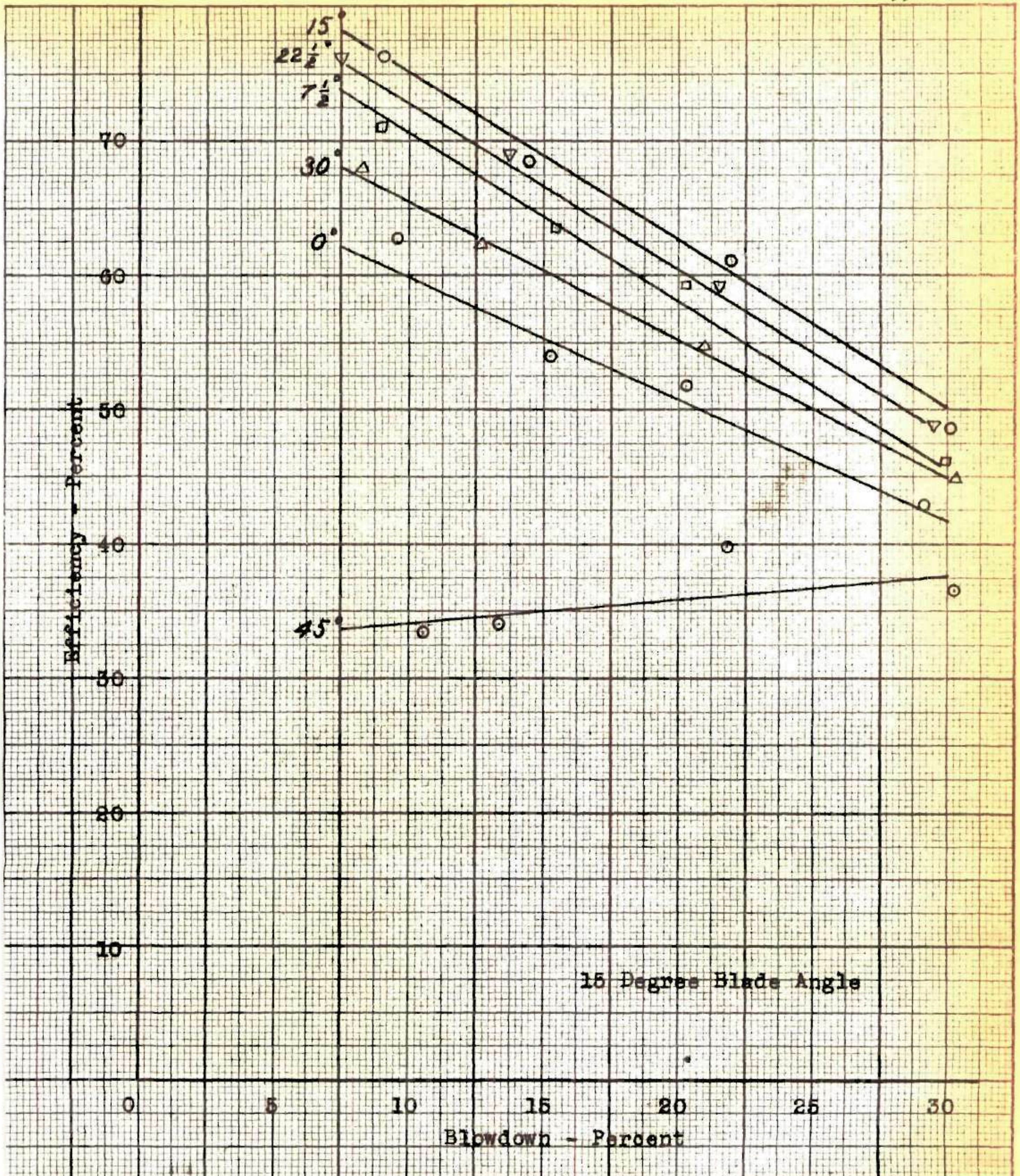


Figure 24

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus BLOWDOWN
James C. Matheson, Jr. October 1951

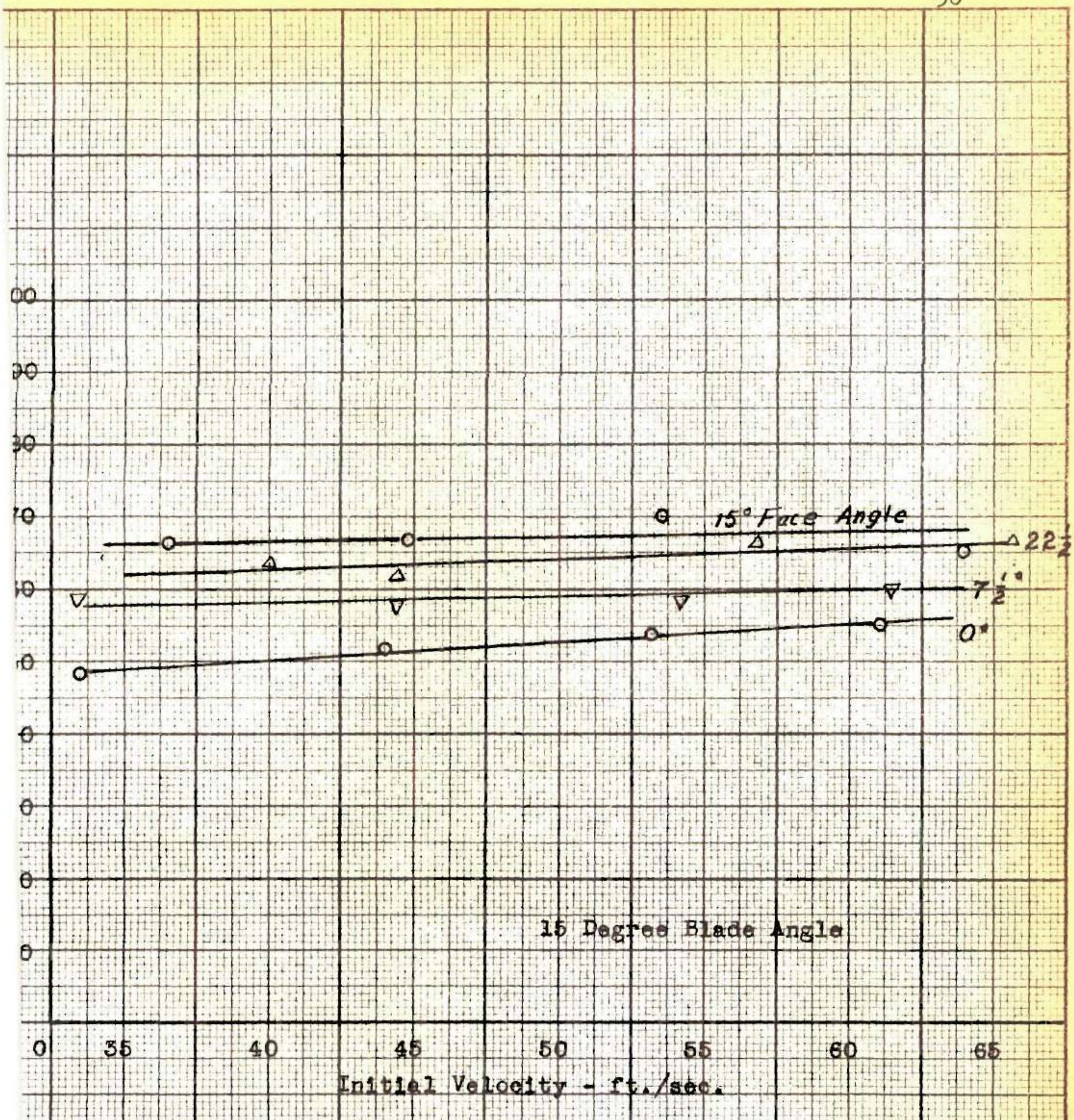


Figure 25

Georgia Institute of Technology
School of Mechanical Engineering
EFFICIENCY versus INITIAL VELOCITY
James C. Matheson, Jr. October 1951

FORM 5009 THE GEORGIA TECH COLLEGE INN

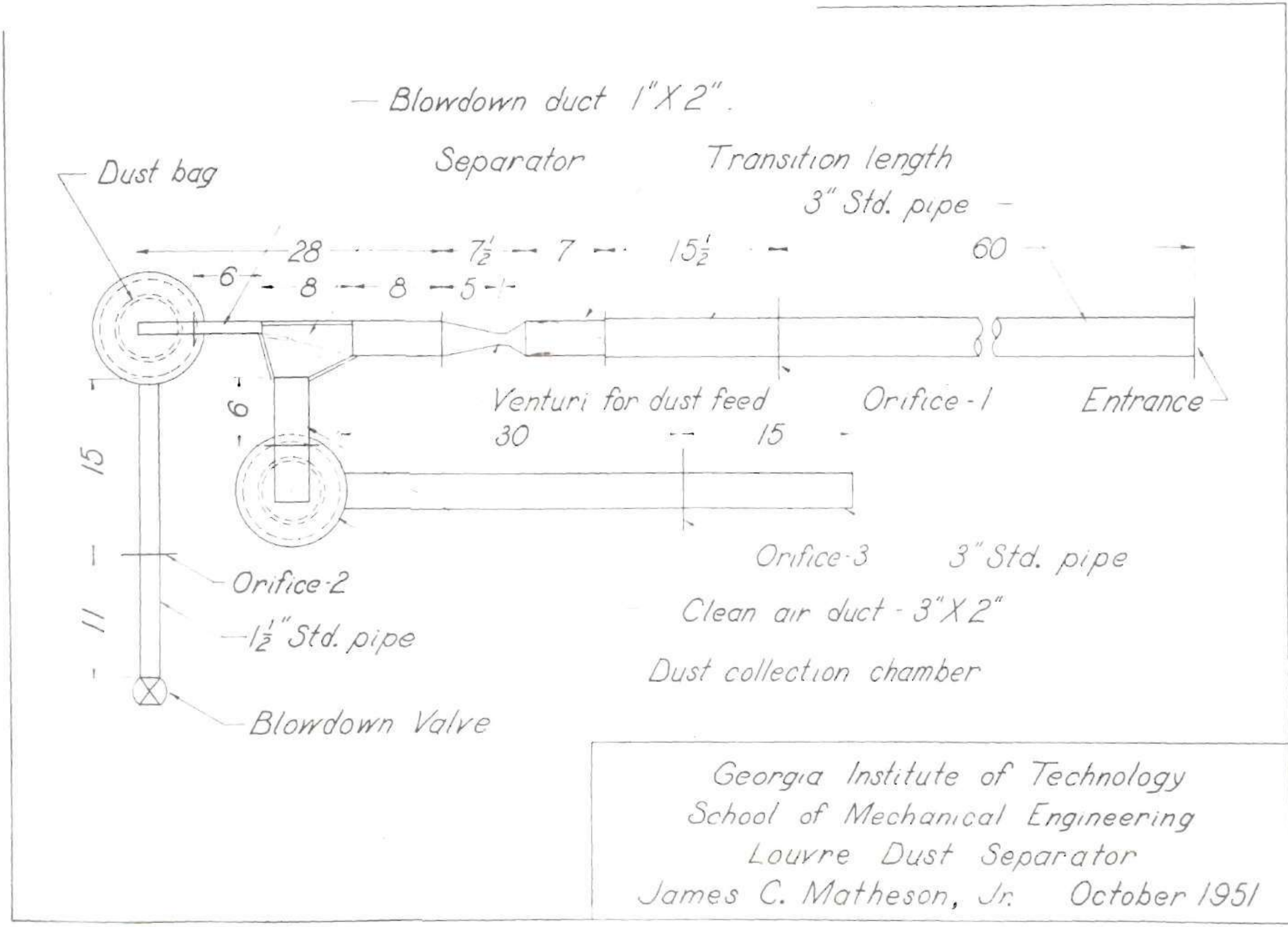

Blowdown duct 1"X2".
Dust bag
Separator
Transition length
3" Std. pipe
28
7½
7
15½
60
6
8
8
5
6
15
11
Venturi for dust feed
Orifice-1
Entrance
30
15
Orifice-3
3" Std. pipe
Orifice-2
1½" Std. pipe
Clean air duct - 3"X2"
Dust collection chamber
Blowdown Valve
Georgia Institute of Technology
School of Mechanical Engineering
Louvre Dust Separator
James C. Matheson, Jr. October 1951

Figure 26

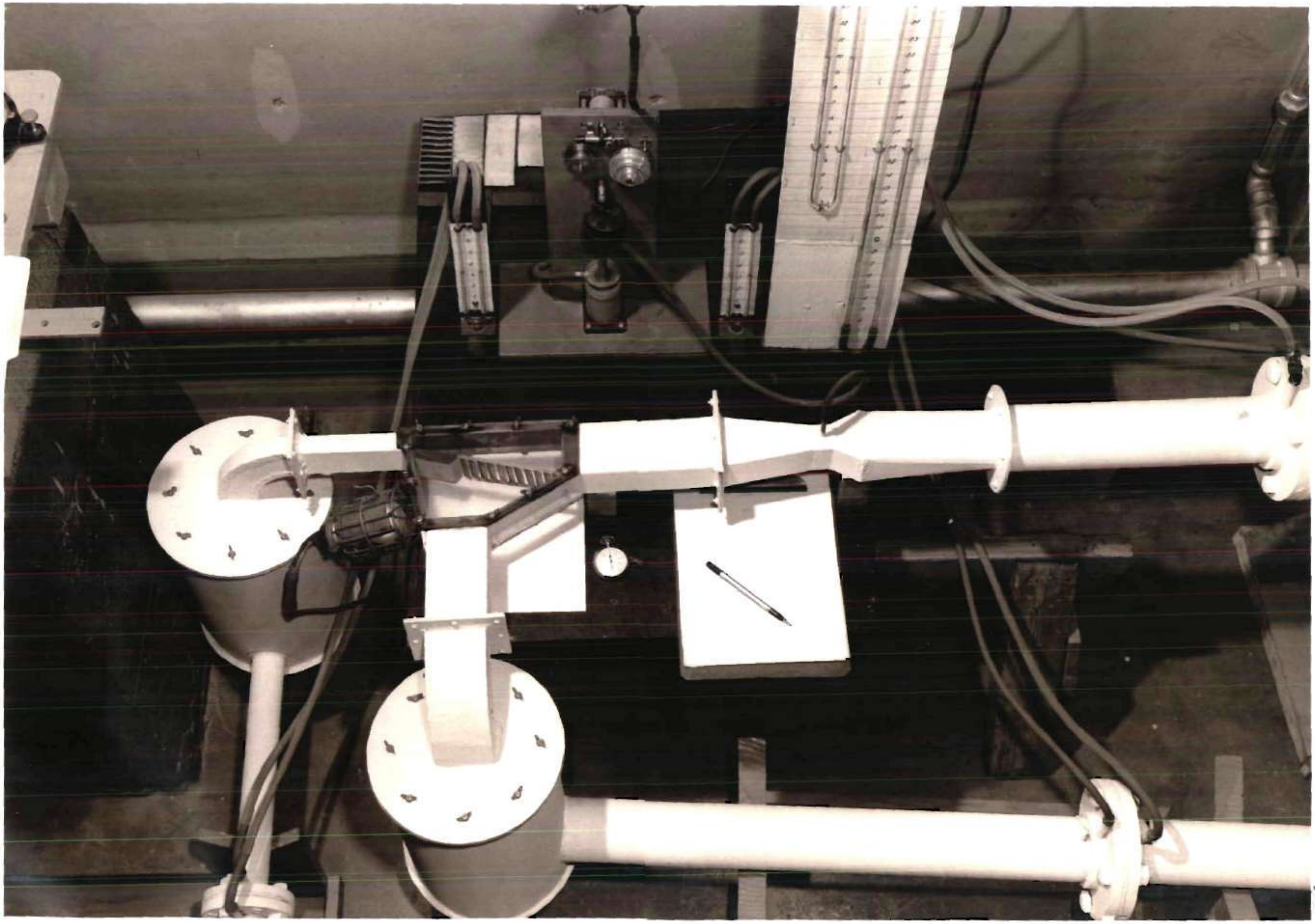


Figure 27

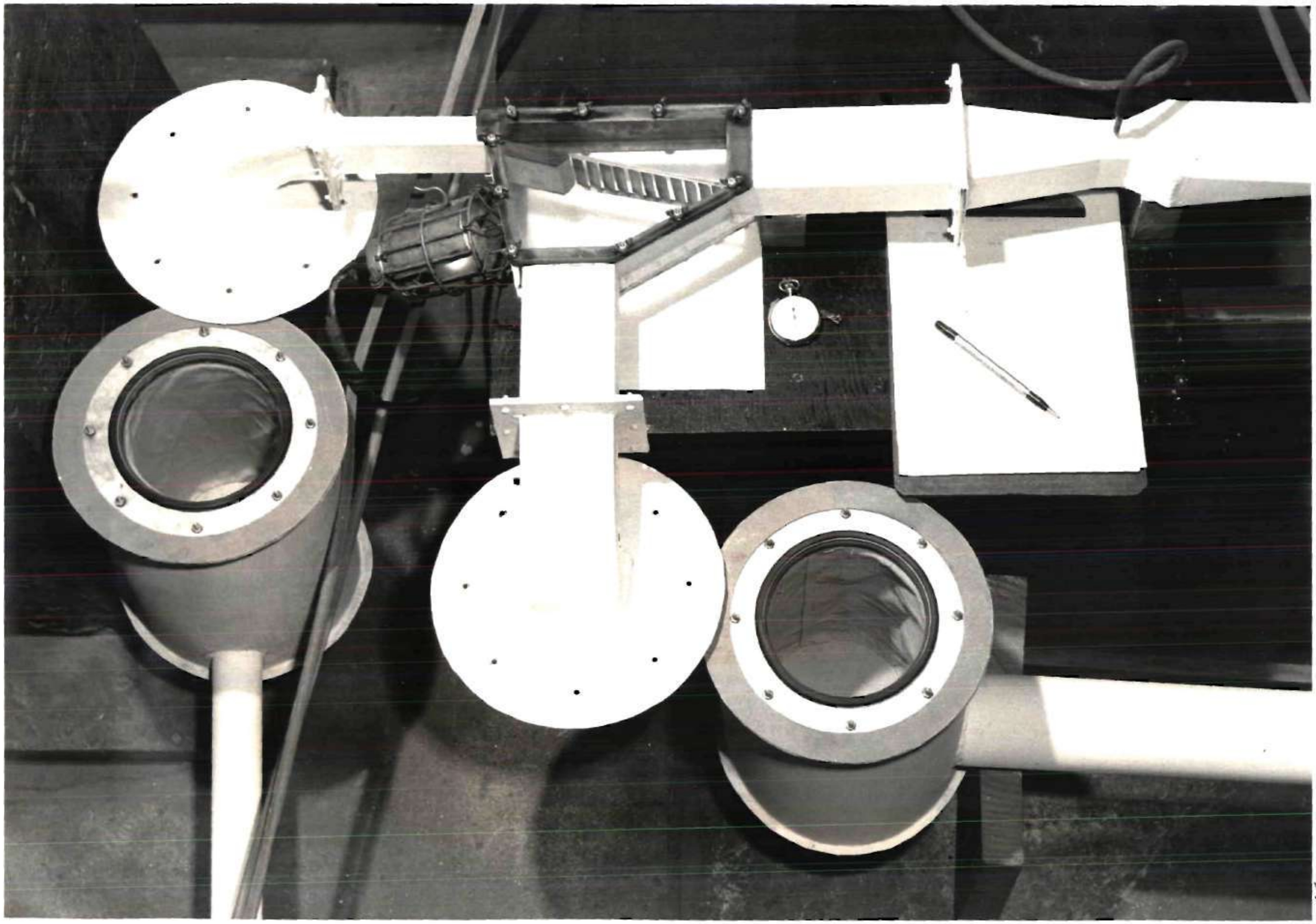


Figure 28

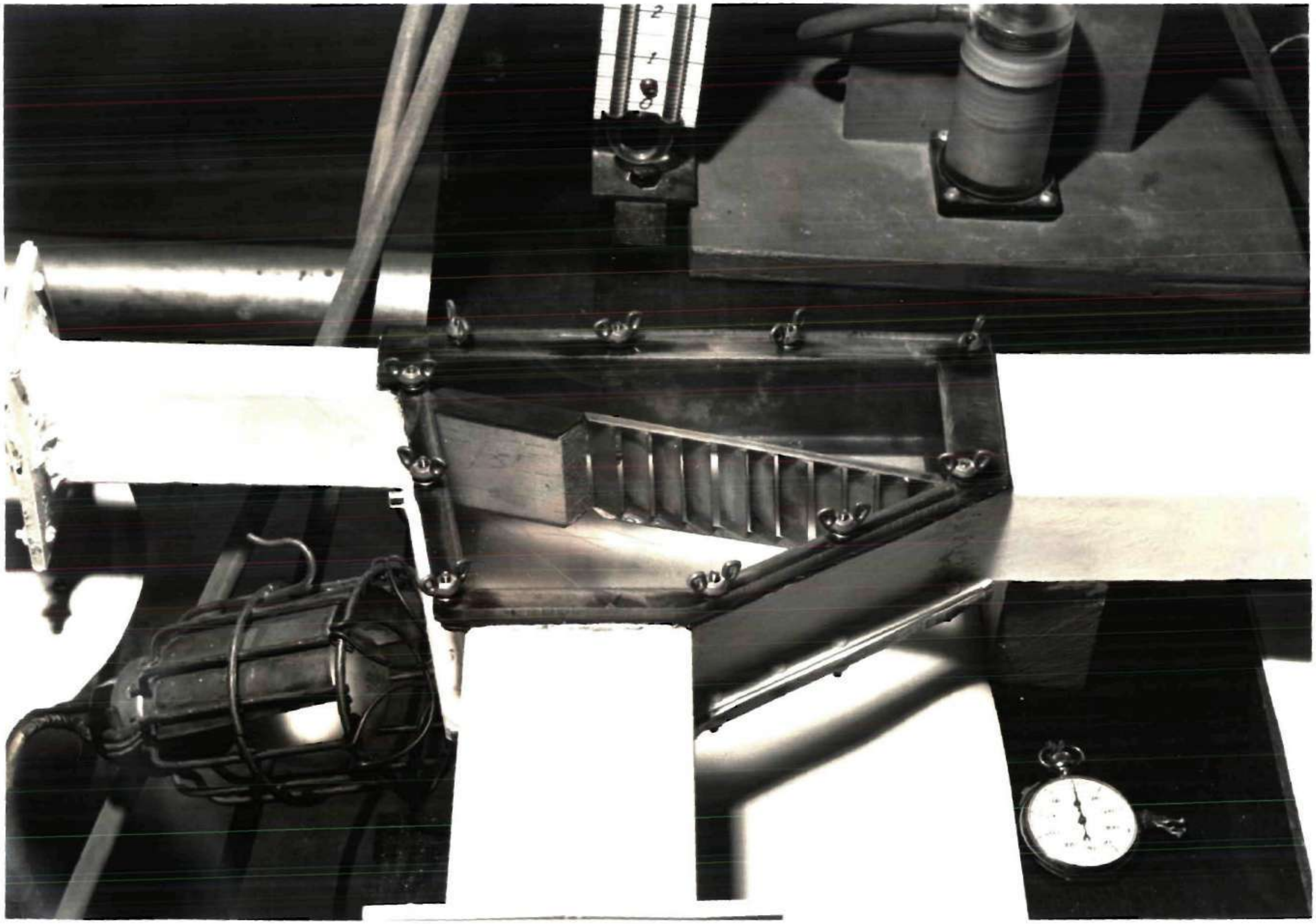


Figure 29

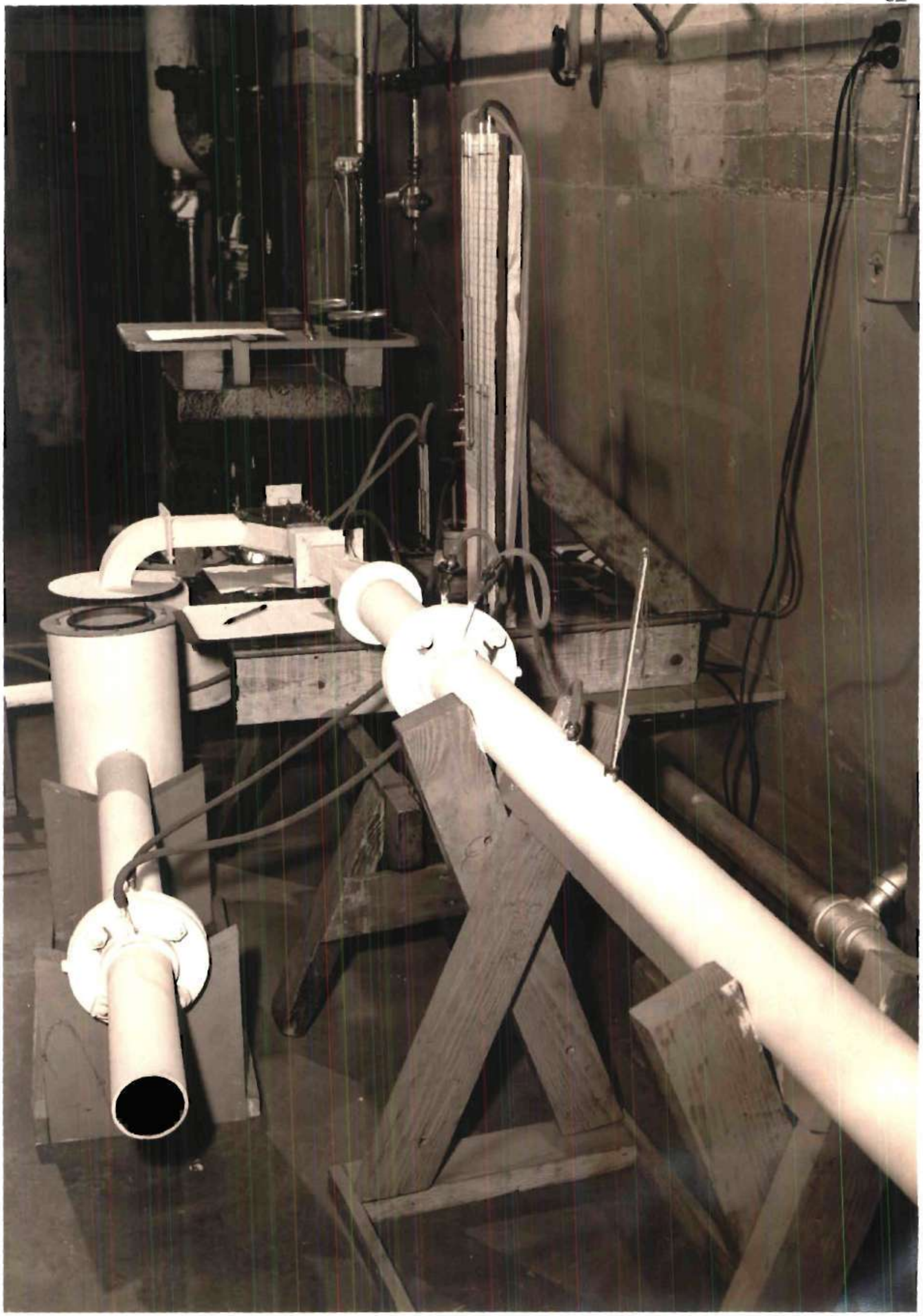
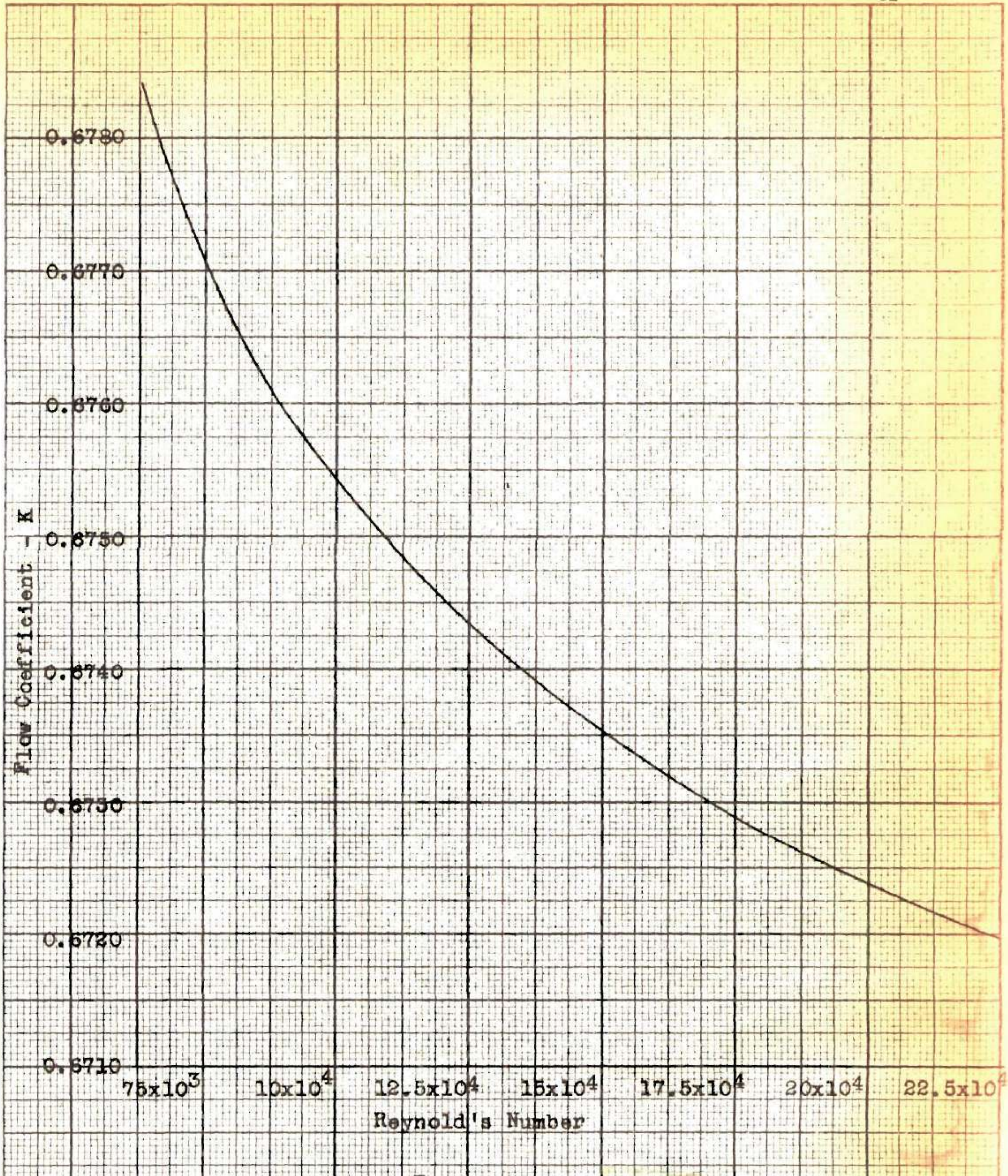


Figure 30


0.6780
0.6770
0.6760
0.6750
0.6740
0.6730
0.6720
0.6710
Flow Coefficient - K
75x10^3
10x10^4
12.5x10^4
15x10^4
17.5x10^4
20x10^4
22.5x10^4
Reynold's Number
Figure 31
Georgia Institute of Technology
School of Mechanical Engineering
FLOW COEFFICIENT - ORIFICE 1
James C. Matheson, Jr. October 1951

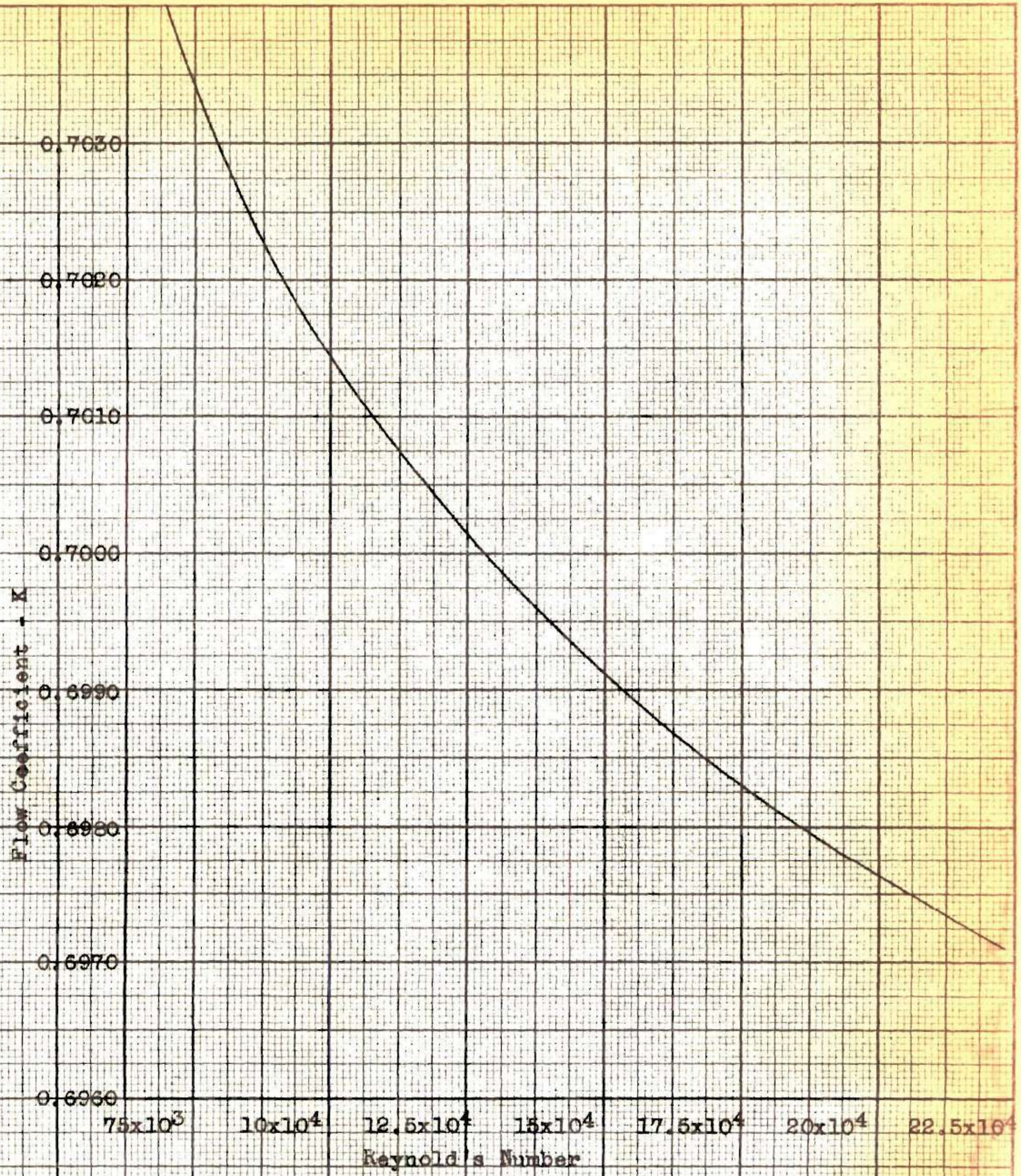


Figure 32

Georgia Institute of Technology
School of Mechanical Engineering
FLOW COEFFICIENT - ORIFICE 2
James C. Matheson, Jr. October 1951

FORM 5000 THE GEORGIA TECH COLLEGE INN

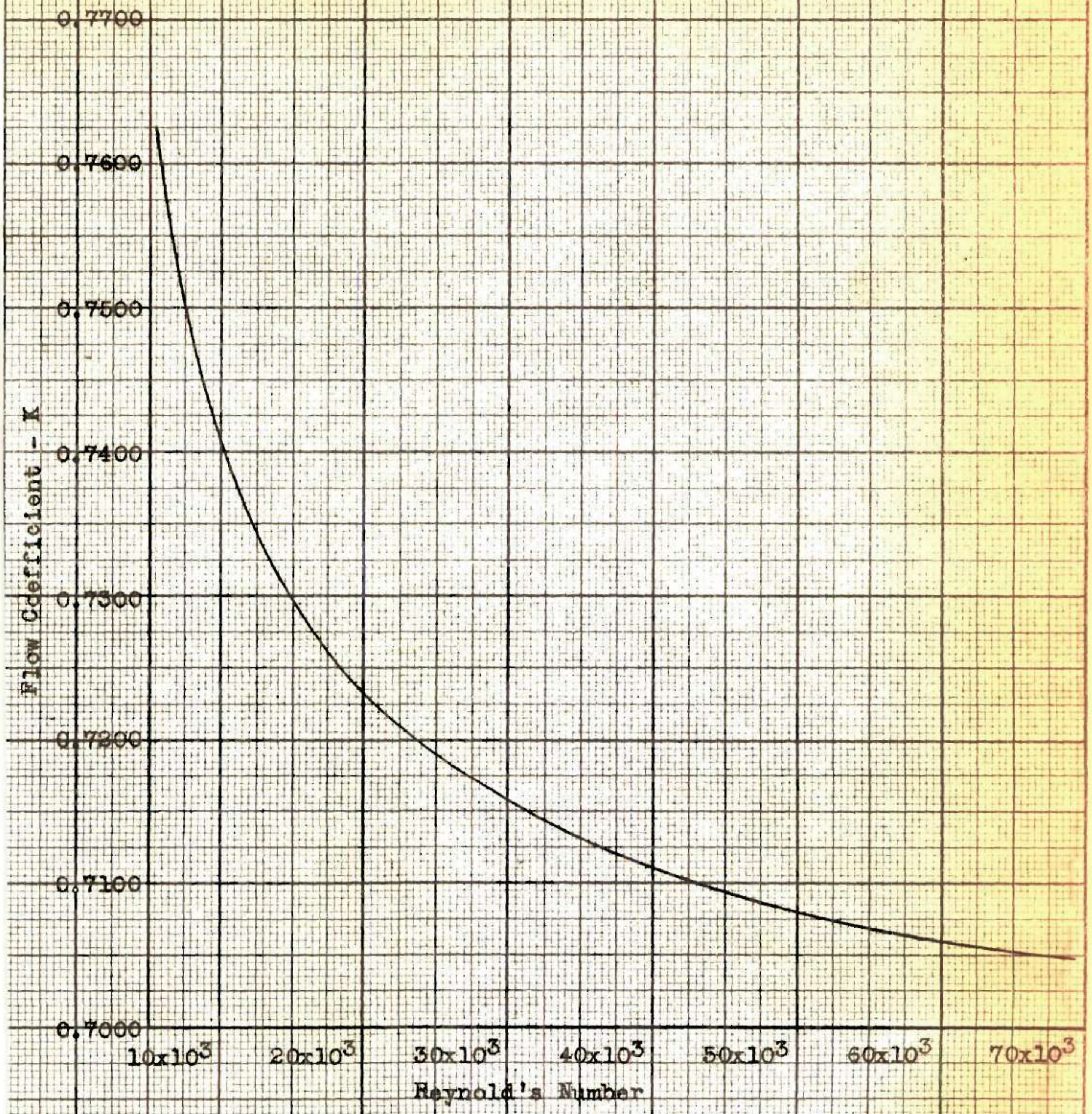


Figure 33

Georgia Institute of Technology
School of Mechanical Engineering
FLOW COEFFICIENT - ORIFICE 3
James C. Matheson, Jr. October 1951

FORM 5000 THE GEORGIA TECH COLLEGE INN

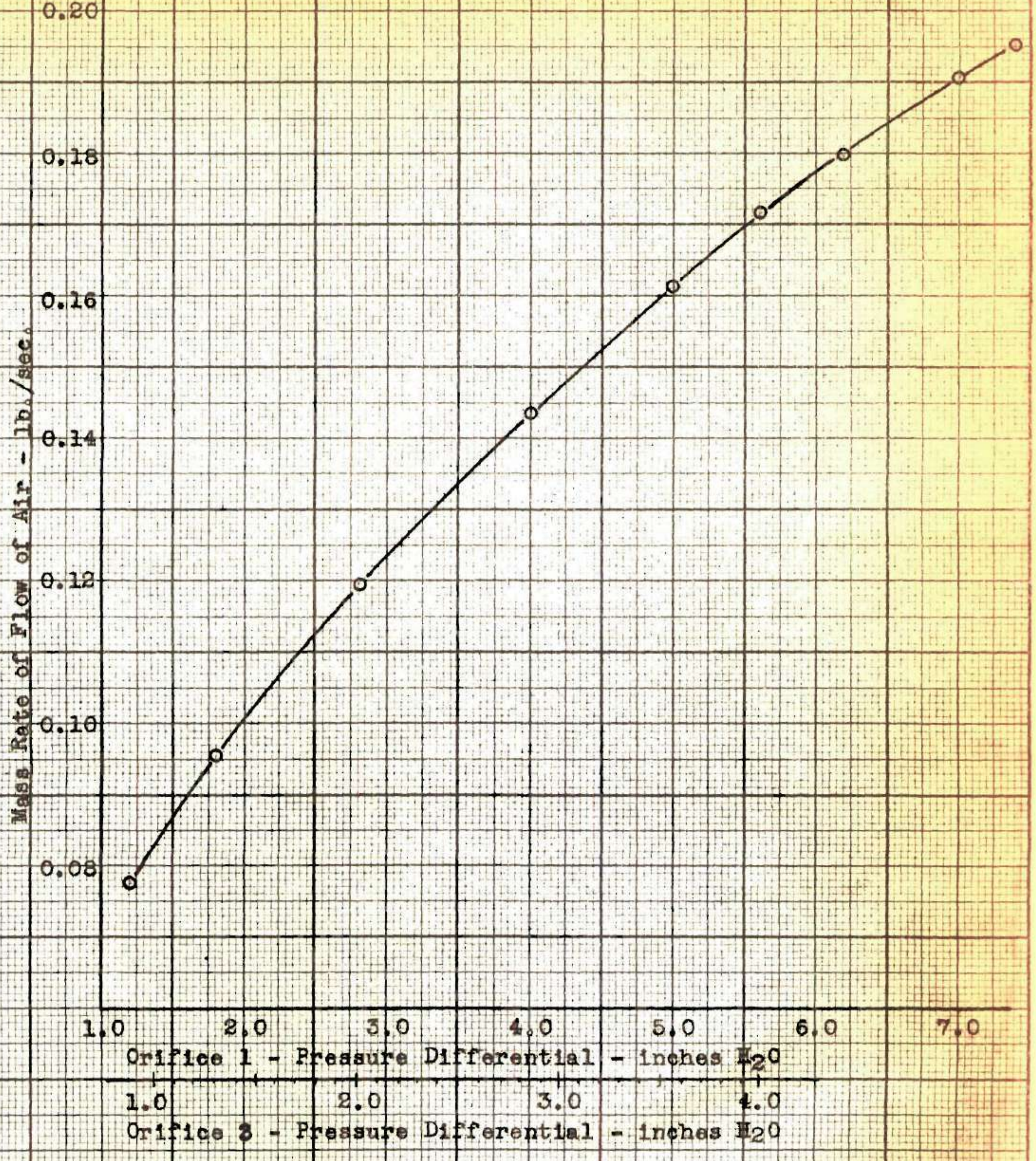
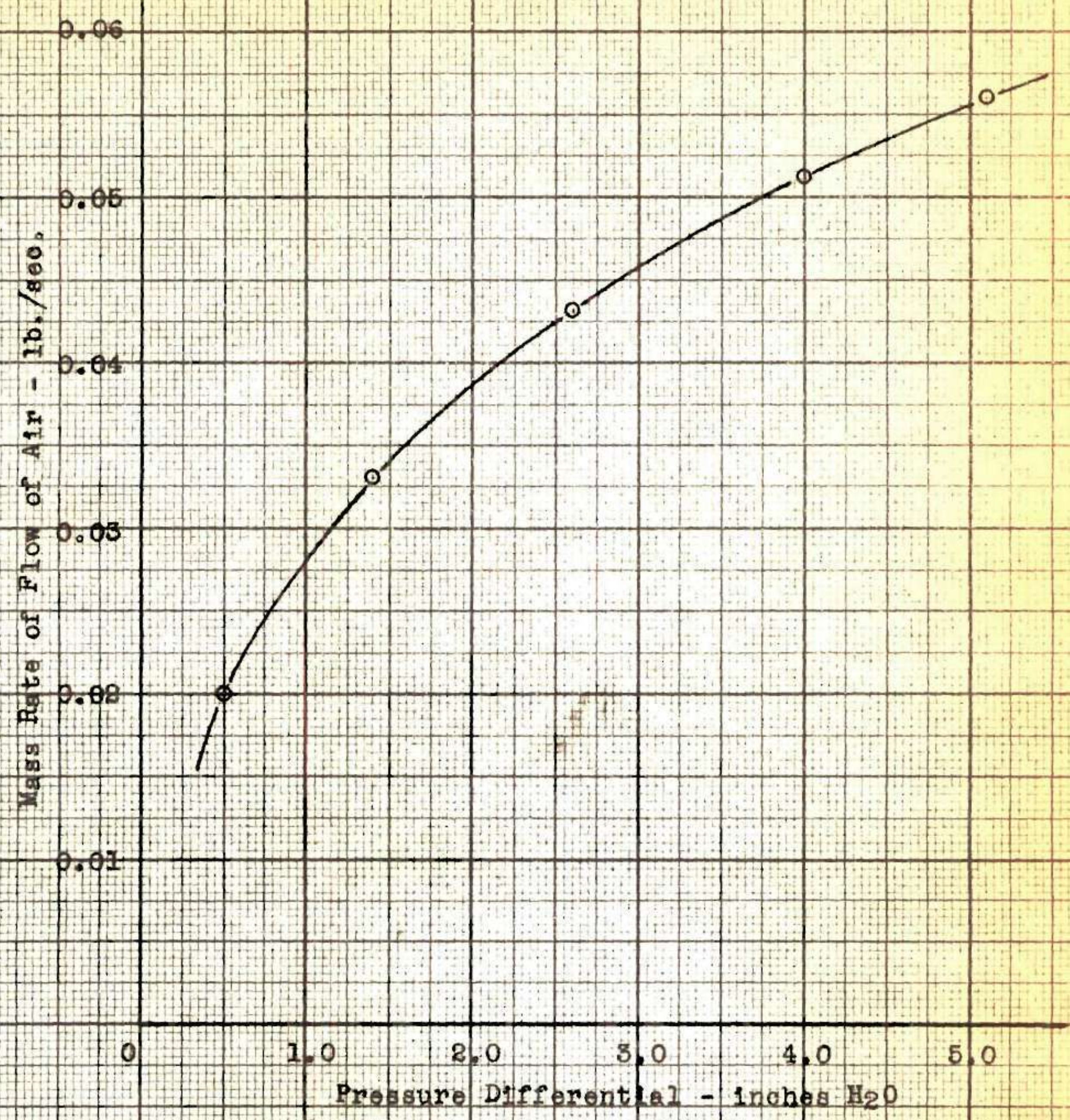


Figure 34

Total Flow - Orifice 1

Clean Air Flow - Orifice 3

Georgia Institute of Technology
School of Mechanical Engineering
ORIFICE CALIBRATION
James C. Matheson, Jr. October 1951



Orifice 3 - Blowdown Air Flow

Figure 35

Georgia Institute of Technology
School of Mechanical Engineering
ORIFICE CALIBRATION
James C. Matheson, Jr. October 1951

APPENDIX B

EXPERIMENTAL RESULTS

TABLE I

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Dust Collected in Bags Clean Air (grams)	Input Less Collected (grams)
			15 Degree Blade Angle			
1	3	0	33.00	27.30	5.20	0.50
2	3	7-1/2	34.40	32.20	1.90	0.30
3	3	15	33.05	31.77	1.15	0.13
4	3	22-1/2	33.15	31.10	1.55	0.50
5	3	30	25.95	24.15	1.55	0.25
6	3	45	28.53	21.15	7.05	0.33
			22-1/2 Degree Blade Angle			
7	3	0	30.80	26.03	4.45	0.32
8	3	7-1/2	29.00	27.00	1.75	0.25
9	3	15	38.70	36.60	1.80	0.30
10	3	22-1/2	37.90	35.90	1.90	0.10
11	3	30	21.80	18.10	3.40	0.30
12	3	45	33.05	19.45	13.50	0.10

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags: Blowdown (grams)	Dust Collected in Bags: Clean Air (grams)	Input Less Collected (grams)
			30 Degree Blade Angle			
13	3	0	30.25	26.25	3.65	0.35
14	3	7-1/2	34.50	32.25	2.20	0.05
15	3	15	37.45	35.33	2.00	0.12
16	3	22-1/2	34.40	31.60	2.75	0.05
17	3	30	39.60	32.80	6.50	0.30
18	3	45	35.70	21.27	14.20	0.23
			15 Degree Blade Angle			
19	3	0	28.20	21.70	6.03	0.47
20	3	7-1/2	36.00	30.23	5.47	0.30
21	3	15	38.82	35.10	3.40	0.32
22	3	22-1/2	34.70	31.67	2.62	0.41
23	3	30	35.80	26.85	8.50	0.45
24	3	45	32.65	15.42	16.75	0.48

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags: Blowdown (grams)	Dust Collected in Bags: Clean Air (grams)	Input Less Collected (grams)
			22-1/2 Degree Blade Angle			
25	3	0	40.50	31.80	8.55	0.15
26	3	7-1/2	35.45	29.90	5.35	0.20
27	3	15	38.25	33.30	4.55	0.40
28	3	22-1/2	36.55	28.80	7.45	0.30
29	3	30	37.13	24.20	12.52	0.41
30	3	45	33.97	13.20	20.50	0.27
			30 Degree Blade Angle			
31	3	0	32.90	24.30	8.30	0.30
32	3	7-1/2	27.80	22.50	4.95	0.35
33	3	15	36.25	30.87	5.10	0.28
34	3	22-1/2	37.60	28.55	8.80	0.25
35	3	30	32.25	19.30	12.80	0.15
36	3	45	33.45	10.70	22.58	0.17

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags: Blowdown (grams)	Dust Collected in Bags: Clean Air (grams)	Input Less Collected (grams)
			15 Degree Blade Angle			
37	3	0	32.78	25.60	6.90	0.28
38	3	7-1/2	34.05	28.70	5.23	0.12
39	3	15	36.97	35.30	1.35	0.32
40	3	22-1/2	35.00	32.00	2.90	0.10
41	3	30	35.97	31.95	3.90	0.12
42	3	45	34.35	18.25	16.00	0.10
			22-1/2 Degree Blade Angle			
43	3	0	34.45	27.20	7.15	0.10
44	3	7-1/2	31.75	27.55	4.00	0.20
45	3	15	33.70	30.85	2.65	0.20
46	3	22-1/2	40.95	35.65	5.13	0.17
47	3	30	39.20	29.28	9.70	0.22
48	3	45	36.35	16.67	19.63	0.05

TABLE I (Continued)

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Clean Air (grams)	Input Less Collected (grams)
			30 Degree Blade Angle			
49	3	0	36.45	29.05	7.23	0.17
50	3	7-1/2	36.05	31.55	4.27	0.23
51	3	15	39.20	35.00	3.85	0.35
52	3	22-1/2	37.00	30.70	6.00	0.30
53	3	30	40.83	27.85	12.61	0.37
54	3	45	35.10	13.80	21.05	0.25
			15 Degree Blade Angle			
55	3	0	35.97	31.90	3.85	0.22
56	3	7-1/2	33.15	30.92	2.00	0.23
57	3	15	35.00	34.48	0.43	0.09
58	3	22-1/2	39.20	38.45	0.57	0.18
59	3	30	35.63	34.17	1.30	0.16
60	3	45	37.52	30.88	6.40	0.24

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Clean Air (grams)	Input Less Collected (grams)
			22-1/2 Degree Blade Angle			
61	3	0	36.45	32.50	3.80	0.15
62	3	7-1/2	32.88	30.77	1.95	0.16
63	3	15	38.15	37.40	0.70	0.05
64	3	22-1/2	37.77	34.65	3.00	0.12
65	3	30	35.15	32.68	2.30	0.17
66	3	45	35.80	23.18	12.40	0.22
			30 Degree Blade Angle			
67	3	0	33.50	30.15	3.20	0.15
68	3	7-1/2	38.20	35.56	2.40	0.24
69	3	15	37.90	36.45	1.27	0.18
70	3	22-1/2	39.20	37.50	1.37	0.33
71	3	30	33.83	29.40	4.27	0.16
72	3	45	38.77	21.77	16.78	0.22

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags: Blowdown (grams)	Dust Collected in Bags: Clean Air (grams)	Input Less Collected (grams)
15 Degree Blade Angle						
73	3	0	21.70	16.33	5.15	0.22
74	3	7-1/2	17.62	14.75	2.80	0.07
75	3	15	16.80.	15.65	0.92	0.23
76	3	22-1/2	26.45	25.15	1.10	0.20
77	3	30	18.50	16.50	1.78	0.22
78	3	45	21.87	16.12	5.78	-0.03
22-1/2 Degree Blade Angle						
79	3	0	24.10	19.05	5.00	0.05
80	3	7-1/2	20.43	17.15	3.07	0.21
81	3	15	24.22	21.67	2.42	0.13
82	3	22-1/2	20.25	17.23	2.82	0.20
83	3	30	23.62	17.75	5.65	0.22
84	3	45	21.63	10.10	11.40	0.13

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags: Blowdown (grams)	Dust Collected in Bags: Clean Air (grams)	Input Less Collected (grams)
30 Degree Blade Angle						
85	3	0	24.45	19.60	4.80	0.05
86	3	7-1/2	22.68	19.55	2.93	0.20
87	3	15	19.00	16.97	1.90	0.13
88	3	22-1/2	19.57	16.90	2.50	0.17
89	3	30	22.20	15.50	6.25	0.45
90	3	45	19.64	7.92	11.75	-0.03
15 Degree Blade Angle						
91	3	0	29.35	22.75	6.50	0.10
92	3	7-1/2	27.00	22.80	3.90	0.30
93	3	15	27.50	25.92	1.40	0.18
94	3	22-1/2	32.80	29.03	3.60	0.17
95	3	30	25.08	22.40	2.33	0.35
96	3	45	16.97	9.35	7.45	0.17

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Dust Collected in Bags Clean Air (grams)	Input Less Collected (grams)
			22-1/2 Degree Blade Angle			
97	3	0	25.35	19.53	5.62	0.20
98	3	7-1/2	19.02	15.60	3.20	0.22
99	3	15	23.10	21.00	2.02	0.08
100	3	22-1/2	26.50	22.90	3.20	0.40
101	3	30	29.00	21.53	7.32	0.15
102	3	45	29.26	13.00	16.07	0.19
			30 Degree Blade Angle			
103	3	0	24.20	18.85	5.30	0.05
104	3	7-1/2	28.15	23.20	4.82	0.13
105	3	15	24.67	22.35	2.10	0.22
106	3	22-1/2	25.05	20.75	4.20	0.10
107	3	30	26.30	17.38	8.68	0.24
108	3	45	23.35	9.20	13.98	0.17

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Dust Collected in Bags Clean Air (grams)	Input Less Collected (grams)
			15 Degree Blade Angle			
109	3	0	37.10	29.50	7.60	0.00
110	3	7-1/2	34.05	29.05	5.00	0.00
111	3	15	42.40	38.90	3.50	0.00
112	3	22-1/2	38.10	35.25	2.85	0.00
113	3	30	41.75	36.95	4.80	0.00
114	3	45	40.05	23.30	16.75	0.00
			22-1/2 Degree Blade Angle			
115	3	0	31.05	24.80	6.15	0.10
116	3	7-1/2	34.33	29.88	4.45	0.00
117	3	15	38.40	35.15	3.25	0.00
118	3	22-1/2	39.80	35.88	3.92	0.00
119	3	30	34.62	26.40	8.22	0.00
120	3	45	41.40	19.20	22.20	0.00

TABLE I (Continued)

Dust Separation Data from Louvre Separator

Run Number	Duration (minutes)	Face Angle (degrees)	Dust Input (grams)	Dust Collected in Bags Blowdown (grams)	Clean Air (grams)	Input Less Collected (grams)
			30 Degree Blade Angle			
121	3	0	39.92	31.00	8.92	0.00
122	3	7-1/2	41.20	34.45	6.75	0.00
123	3	15	39.55	36.35	3.20	0.00
124	3	22-1/2	34.15	28.33	5.82	0.00
125	3	30	31.52	21.20	10.32	0.00
126	3	45	33.65	13.20	20.45	0.00

TABLE II

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
1	29.08	80	70	88	27.2	5.8	1.7	2.7
2	29.08	80	70	88	27.0	5.8	1.6	2.7
3	29.06	86	75	96	29.0	5.9	1.7	2.6
4	29.08	80	70	88	27.0	6.1	1.7	2.7
5	29.08	80	70	88	27.4	6.0	1.7	2.7
6	29.08	80	70	90	30.0	5.6	1.7	2.5
7	29.22	80	70	92	28.2	5.8	1.7	2.7
8	29.22	80	70	92	27.6	6.0	1.7	2.7
9	29.06	86	74	97	26.3	6.0	1.7	2.7
10	29.22	82	70	92	23.5	5.8	1.7	2.7
11	29.21	82	70	92	23.0	5.9	1.7	2.7
12	29.21	82	70	92	25.5	5.8	1.7	2.7
13	29.21	84	70	92	28.5	6.0	1.7	2.7
14	29.21	84	70	93	27.0	5.9	1.7	2.7
15	29.21	84	70	94	27.2	5.9	1.7	2.7
16	29.22	80	70	92	23.9	5.9	1.7	2.7
17	29.22	80	70	91	23.8	5.9	1.7	2.7
18	29.22	80	70	92	24.9	5.8	1.7	2.7

TABLE II (Continued)

Air Flow Data from Louvre Separator

Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
19	29.18	80	72	93	30.0	5.3	0.3	3.1
20	29.18	82	73	93	30.0	5.5	0.3	3.25
21	29.15	82	74	94	31.0	5.2	0.3	3.1
22	29.15	82	74	92	28.2	5.9	0.3	3.6
23	29.15	82	74	93	30.0	5.8	0.3	3.5
24	29.15	82	74	94	31.0	4.7	0.3	2.7
25	29.10	80	72	91	30.0	5.6	0.3	3.4
26	29.10	80	72	88	29.8	5.8	0.3	3.5
27	29.10	80	72	89	30.0	5.8	0.3	3.4
28	29.10	80	72	89	25.0	5.8	0.3	3.45
29	29.10	80	72	90	24.7	5.8	0.3	3.4
30	29.10	80	72	92	28.0	5.8	0.3	3.45
31	29.10	86	74	92	30.0	5.8	0.3	3.4
32	29.10	86	74	95	28.5	5.9	0.3	3.6
33	29.10	86	74	96	28.5	5.9	0.3	3.6
34	29.10	86	74	95	25.0	5.9	0.3	3.6
35	29.10	90	78	98	24.2	5.9	0.3	3.5
36	29.10	90	78	98	25.0	5.9	0.3	3.5

TABLE II (Continued)

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
37	29.06	86	75	98	30.0	5.2	0.7	2.7
38	28.96	88	75	94	29.6	5.4	0.6	2.8
39	28.96	88	75	95	29.0	5.3	0.7	2.8
40	28.96	89	76	97	27.0	5.8	0.7	3.1
41	28.96	91	80	99	26.6	5.7	0.7	3.1
42	28.96	92	81	100	31.0	4.8	0.5	2.6
43	29.04	84	74	95	30.2	5.85	0.8	3.1
44	29.04	84	74	95	29.4	6.0	0.85	3.1
45	29.04	85	75	95	30.0	5.85	0.85	3.05
46	29.04	87	75	96	24.4	5.9	0.7	3.15
47	29.04	86	75	96	24.3	5.95	0.8	3.15
48	29.02	88	76	95	26.6	5.9	0.8	3.1
49	29.02	88	76	95	27.6	5.85	0.8	3.15
50	29.02	88	76	98	26.4	5.85	0.8	3.05
51	29.02	90	77	98	26.8	5.85	0.8	3.05
52	29.25	82	64	91	23.6	6.0	0.8	3.05
53	29.25	82	64	92	24.3	5.95	0.85	3.05
54	29.25	82	64	92	24.9	6.05	0.9	3.05

TABLE II (Continued)

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
55	29.25	84	67	94	30.0	6.10	3.75	2.25
56	29.25	84	67	94	29.2	6.25	3.75	2.25
57	29.25	84	67	94	32.0	6.15	3.75	2.20
58	29.25	86	68	94	23.9	6.15	3.75	2.25
59	29.25	86	68	95	24.2	6.30	3.65	2.25
60	29.25	86	68	96	28.8	6.05	3.70	2.15
61	29.27	84	70	93	24.3	6.05	3.65	2.25
62	29.27	85	70	95	24.4	6.05	3.65	2.20
63	29.27	85	70	95	24.0	6.05	3.65	2.20
64	29.14	81	68	91	19.9	6.05	3.65	2.20
65	29.14	82	69	91	19.2	6.15	3.65	2.20
66	29.14	82	70	93	22.3	6.05	3.65	2.20
67	29.12	82	70	94	23.2	6.05	3.65	2.20
68	29.06	84	72	93	23.0	6.05	3.55	2.25
69	29.06	84	71	93	22.5	6.15	3.55	2.20
70	29.06	84	71	94	19.0	6.05	3.60	2.20
71	29.06	85	71	94	18.6	6.05	3.60	2.20
72	29.06	85	71	95	20.7	6.05	3.80	2.10

TABLE II (Continued)

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
73	28.96	83	70	96	15.4	1.95	0.35	1.00
74	28.96	84	70	94	15.0	1.95	0.35	1.05
75	28.96	84	70	93	15.1	2.00	0.35	1.10
76	28.87	86	70	90	12.7	2.05	0.35	1.10
77	28.87	86	70	92	12.8	1.95	0.35	1.05
78	28.87	88	72	94	15.0	1.95	0.35	1.05
79	28.89	82	70	91	12.9	1.95	0.30	1.00
80	28.89	82	70	91	13.0	1.95	0.35	1.05
81	28.89	84	70	92	13.0	1.95	0.35	1.05
82	28.89	84	70	92	11.4	1.95	0.35	1.05
83	28.89	84	70	93	11.4	1.95	0.35	1.05
84	28.89	84	70	94	12.2	1.95	0.35	1.00
85	28.87	86	72	93	12.8	1.95	0.35	1.05
86	28.87	86	72	93	12.9	1.95	0.35	1.05
87	28.87	86	72	95	12.4	1.95	0.35	1.05
88	28.87	88	72	94	10.2	1.95	0.35	1.00
89	28.87	88	72	96	10.4	1.95	0.35	1.00
90	28.87	88	72	97	11.2	1.95	0.35	1.00

TABLE II (Continued)

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)
91	28.96	84	71	95	25.6	3.55	0.50	1.80
92	28.96	84	71	95	23.1	3.55	0.50	1.80
93	28.96	84	70	95	23.1	3.50	0.50	1.80
94	28.96	85	71	96	20.4	3.50	0.50	1.80
95	28.96	85	71	96	20.4	3.50	0.50	1.80
96	28.96	88	72	94	25.8	3.50	0.50	1.80
97	28.95	88	72	96	22.1	3.55	0.50	1.80
98	28.95	89	70	97	21.7	3.55	0.50	1.80
99	28.95	88	71	98	20.4	3.55	0.50	1.80
100	28.95	90	71	98	17.7	3.55	0.50	1.80
101	28.95	90	72	99	18.1	3.55	0.50	1.80
102	28.95	90	72	99	19.3	3.55	0.50	1.80
103	29.06	84	73	95	20.1	3.55	0.50	1.80
104	29.06	84	74	95	19.7	3.55	0.50	1.80
105	29.06	85	74	95	18.0	3.55	0.50	1.80
106	29.06	85	74	95	15.3	3.55	0.50	1.80
107	29.06	85	74	96	16.1	3.55	0.50	1.80
108	29.06	86	74	96	16.5	3.55	0.50	1.80

TABLE II (Continued)

Air Flow Data from Louvre Separator

Run Number	Barom. (in. Hg)	T_d (F)	T_w (F)	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)
109	29.02	90	74	98	27.2	6.75	1.00
110	29.02	90	74	97	27.0	6.80	1.00
111	29.02	90	74	99	25.9	7.40	1.05
112	29.02	90	74	101	18.8	7.45	1.05
113	29.02	90	75	100	18.3	7.40	1.05
114	29.02	89	75	100	27.1	6.80	1.00
115	29.02	86	75	95	22.5	7.40	1.05
116	29.02	86	75	95	19.3	7.40	1.05
117	29.02	87	75	96	19.2	7.40	1.05
118	29.02	87	75	97	12.6	7.40	1.05
119	29.02	88	76	96	11.7	7.40	1.05
120	29.02	88	76	97	13.7	7.40	1.05
121	29.02	88	75	98	18.8	7.40	1.05
122	29.02	90	75	98	16.9	7.40	1.05
123	29.02	90	75	96	15.7	7.40	1.05
124	29.02	90	75	98	9.9	7.40	1.05
125	29.02	90	75	99	9.3	7.40	1.05
126	29.02	90	75	99	10.5	7.40	1.05

TABLE III

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
1	0.1745	0.0360	0.1395	0.0350	20.30	55.8	22.4
2	0.1745	0.0350	0.1395	0.0350	20.30	55.8	22.4
3	0.1750	0.0360	0.1365	0.0385	22.00	56.6	24.9
4	0.1780	0.0360	0.1395	0.0385	21.60	57.0	24.7
5	0.1766	0.0360	0.1395	0.0371	21.00	56.5	23.7
6	0.1710	0.0360	0.1337	0.0373	21.80	54.5	23.8
7	0.1745	0.0360	0.1395	0.0350	20.02	55.7	22.4
8	0.1766	0.0360	0.1395	0.0370	20.95	56.5	23.7
9	0.1766	0.0360	0.1395	0.0370	20.95	57.5	24.2
10	0.1745	0.0360	0.1395	0.0350	20.02	56.5	22.7
11	0.1750	0.0360	0.1395	0.0355	20.30	56.7	23.0
12	0.1745	0.0360	0.1395	0.0350	20.02	56.2	22.6
13	0.1766	0.0360	0.1395	0.0370	20.95	56.5	23.7
14	0.1750	0.0360	0.0395	0.0355	20.30	56.3	22.8
15	0.1750	0.0360	0.1395	0.0355	20.30	56.4	22.9
16	0.1750	0.0360	0.1395	0.0355	20.30	56.7	23.0
17	0.1750	0.0360	0.1395	0.0355	20.30	56.7	23.0
18	0.1745	0.0360	0.1395	0.0350	20.02	56.2	22.6

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
19	0.1660	0.0150	0.1500	0.0160	9.64	53.0	10.2
20	0.1690	0.0150	0.1535	0.0155	9.17	54.0	9.9
21	0.1650	0.0150	0.1500	0.0150	9.10	52.7	9.6
22	0.1750	0.0150	0.1620	0.0130	7.43	56.1	8.3
23	0.1740	0.0150	0.1595	0.0145	8.34	55.6	9.3
24	0.1560	0.0150	0.1395	0.0165	10.56	49.9	10.6
25	0.1710	0.0150	0.1570	0.0140	8.19	54.5	8.9
26	0.1740	0.0150	0.1595	0.0145	8.34	55.3	9.2
27	0.1740	0.0150	0.1570	0.0170	9.77	55.4	10.8
28	0.1740	0.0150	0.1580	0.0160	9.20	56.0	10.3
29	0.1740	0.0150	0.1570	0.0170	9.77	56.1	11.0
30	0.1740	0.0150	0.1580	0.0160	9.20	55.9	10.3
31	0.1740	0.0150	0.1570	0.0170	9.77	55.6	10.9
32	0.1750	0.0150	0.1620	0.0130	7.44	56.5	8.4
33	0.1750	0.0150	0.1620	0.0130	7.44	56.5	8.4
34	0.1750	0.0150	0.1620	0.0130	7.44	56.9	8.5
35	0.1750	0.0150	0.1595	0.0155	8.86	57.4	10.2
36	0.1750	0.0150	0.1595	0.0155	8.86	57.3	10.1

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
37	0.1645	0.0237	0.1395	0.0250	15.20	53.4	16.2
38	0.1680	0.0220	0.1420	0.0260	15.46	54.2	16.8
39	0.1660	0.0237	0.1420	0.0240	14.46	53.6	15.5
40	0.1740	0.0237	0.1500	0.0240	13.70	56.8	15.6
41	0.1720	0.0237	0.1500	0.0220	12.65	56.4	14.5
42	0.1580	0.0200	0.1370	0.0210	13.30	51.7	13.7
43	0.1745	0.0252	0.1500	0.0245	14.03	56.2	15.8
44	0.1766	0.0260	0.1500	0.0266	15.06	57.0	17.2
45	0.1745	0.0260	0.1485	0.0260	14.90	56.2	16.8
46	0.1750	0.0235	0.1510	0.0240	13.71	57.3	15.7
47	0.1760	0.0252	0.1510	0.0250	14.20	57.6	16.4
48	0.1750	0.0252	0.1500	0.0250	14.28	56.9	16.2
49	0.1745	0.0252	0.1510	0.0235	13.50	56.5	15.2
50	0.1745	0.0252	0.1485	0.0260	14.90	57.1	17.0
51	0.1745	0.0252	0.1485	0.0260	14.90	57.0	17.0
52	0.1766	0.0252	0.1485	0.0281	15.90	57.4	18.3
53	0.1760	0.0260	0.1485	0.0275	15.60	57.3	17.9
54	0.1773	0.0265	0.1485	0.0288	16.25	57.5	18.7

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
55	0.1780	0.0500	0.1263	0.0517	29.05	56.8	33.0
56	0.1800	0.0500	0.1263	0.0537	29.85	57.6	34.4
57	0.1790	0.0500	0.1252	0.0538	30.05	56.9	34.3
58	0.1790	0.0500	0.1263	0.0527	29.45	58.0	34.2
59	0.1810	0.0487	0.1263	0.0547	30.25	58.6	35.5
60	0.1773	0.0492	0.1235	0.0538	30.30	57.1	34.7
61	0.1775	0.0495	0.1265	0.0510	28.75	57.3	33.0
62	0.1775	0.0495	0.1250	0.0525	29.60	57.5	34.0
63	0.1775	0.0495	0.1250	0.0525	29.60	57.5	34.0
64	0.1775	0.0495	0.1250	0.0525	29.60	57.7	34.2
65	0.1790	0.0495	0.1250	0.0540	30.15	58.4	35.2
66	0.1775	0.0495	0.1250	0.0525	29.60	57.5	34.1
67	0.1775	0.0495	0.1250	0.0525	29.60	57.9	34.3
68	0.1775	0.0488	0.1265	0.0510	28.75	58.0	33.3
69	0.1790	0.0488	0.1250	0.0540	30.15	58.4	35.3
70	0.1775	0.0490	0.1250	0.0525	29.60	58.5	34.6
71	0.1775	0.0490	0.1250	0.0525	29.60	58.4	34.6
72	0.1775	0.0500	0.1220	0.0555	31.25	58.5	34.6

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
73	0.1000	0.0165	0.0825	0.0175	17.50	33.5	11.7
74	0.1000	0.0165	0.0850	0.0150	15.00	33.4	10.0
75	0.1100	0.0165	0.0875	0.0225	20.40	36.6	15.0
76	0.1200	0.0165	0.0875	0.0325	27.10	40.1	21.7
77	0.1000	0.0165	0.0850	0.0150	15.00	33.6	10.1
78	0.1000	0.0165	0.0850	0.0150	15.00	33.5	10.1
79	0.1000	0.0160	0.0825	0.0175	17.50	33.5	11.7
80	0.1000	0.0165	0.0850	0.0150	15.00	33.5	10.0
81	0.1000	0.0165	0.0850	0.0150	15.00	33.5	10.0
82	0.1000	0.0165	0.0850	0.0150	15.00	33.6	10.1
83	0.1000	0.0165	0.0850	0.0150	15.00	33.7	10.1
84	0.1000	0.0165	0.0825	0.0175	17.50	33.7	11.8
85	0.1000	0.0165	0.0850	0.0150	15.00	33.6	10.1
86	0.1000	0.0165	0.0850	0.0150	15.00	33.6	10.1
87	0.1000	0.0165	0.0850	0.0150	15.00	33.8	10.1
88	0.1000	0.0165	0.0825	0.0175	17.50	33.9	11.9
89	0.1000	0.0165	0.0825	0.0175	17.50	34.1	11.9
90	0.1000	0.0165	0.0825	0.0175	17.50	34.1	11.9

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2^* (lb./sec.)	w_3 (lb./sec.)	w_2 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
91	0.1350	0.0200	0.1130	0.0220	16.30	44.0	14.4
92	0.1350	0.0200	0.1130	0.0220	16.30	44.4	14.5
93	0.1340	0.0200	0.1130	0.0210	15.67	44.0	13.8
94	0.1340	0.0200	0.1130	0.0210	15.67	44.4	13.9
95	0.1340	0.0200	0.1130	0.0210	15.67	44.4	13.9
96	0.1340	0.0200	0.1130	0.0210	15.67	43.6	13.7
97	0.1350	0.0200	0.1130	0.0220	16.30	44.6	14.5
98	0.1350	0.0200	0.1130	0.0220	16.30	44.7	14.6
99	0.1350	0.0200	0.1130	0.0220	16.30	44.8	14.6
100	0.1350	0.0200	0.1130	0.0220	16.30	45.2	14.7
101	0.1350	0.0200	0.1130	0.0220	16.30	45.1	14.7
102	0.1350	0.0200	0.1130	0.0220	16.30	45.1	14.7
103	0.1350	0.0200	0.1130	0.0220	16.30	44.5	14.5
104	0.1350	0.0200	0.1130	0.0220	16.30	44.5	14.5
105	0.1350	0.0200	0.1130	0.0220	16.30	44.8	14.6
106	0.1350	0.0200	0.1130	0.0220	16.30	45.1	14.7
107	0.1350	0.0200	0.1130	0.0220	16.30	45.1	14.7
108	0.1350	0.0200	0.1130	0.0220	16.30	45.0	14.7

TABLE III (Continued)

Air Flow Results

Run Number	w_1 (lb./sec.)	w_2 (lb./sec.)	w_3 (lb./sec.)	Blowdown (per cent)	V_1 (ft./sec.)	V_2 (ft./sec.)
109	0.1870	0.0280	0.1590	15.00	61.1	18.3
110	0.1880	0.0280	0.1600	14.90	61.4	18.3
111	0.1950	0.0287	0.1663	14.70	64.0	18.7
112	0.1960	0.0287	0.1673	14.65	65.7	19.3
113	0.1950	0.0287	0.1663	14.70	65.3	19.2
114	0.1880	0.0280	0.1600	14.90	61.6	18.4
115	0.1950	0.0287	0.1663	14.70	64.0	18.8
116	0.1950	0.0287	0.1663	14.70	64.5	19.0
117	0.1950	0.0287	0.1663	14.70	64.6	19.0
118	0.1950	0.0287	0.1663	14.70	65.8	19.4
119	0.1950	0.0287	0.1663	14.70	65.9	19.4
120	0.1950	0.0287	0.1663	14.70	65.6	19.3
121	0.1950	0.0287	0.1663	14.70	65.0	19.1
122	0.1950	0.0287	0.1663	14.70	65.3	19.2
123	0.1950	0.0287	0.1663	14.70	65.3	19.2
124	0.1950	0.0287	0.1663	14.70	66.5	19.6
125	0.1950	0.0287	0.1663	14.70	66.5	19.6
126	0.1950	0.0287	0.1663	14.70	66.5	19.6

TABLE IV

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	$\mathcal{E}$ (per cent)
1	3.98×10^{-4}	3.35×10^{-4}	2.28×10^{-3}	9.57×10^{-3}	84.0	51.7
2	4.18	3.95	2.39	11.29	94.5	60.2
3	4.03	3.89	2.30	10.11	96.5	58.1
4	4.00	3.81	2.25	9.90	95.3	57.5
5	3.15	2.96	1.78	7.96	93.8	57.0
6	3.58	2.59	2.09	6.95	72.4	39.5
7	3.74	3.19	2.15	9.12	85.4	52.1
8	3.52	3.31	2.00	8.95	94.0	57.8
9	4.70	4.48	2.66	12.10	95.4	59.0
10	4.63	4.39	2.65	12.55	95.0	59.6
11	2.63	2.22	1.50	6.26	84.2	51.6
12	4.03	2.38	2.31	6.81	59.2	31.2
13	3.66	3.22	2.08	8.69	87.9	52.9
14	4.22	3.95	2.41	11.12	93.6	58.5
15	4.57	4.32	2.61	12.17	94.7	59.2
16	4.20	3.87	2.40	10.90	92.1	57.3
17	4.81	4.02	2.75	11.32	83.5	50.5
18	4.34	2.61	2.49	7.46	60.0	32.0

TABLE IV (Continued)

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	ε (per cent)
19	3.39×10^{-4}	2.66×10^{-4}	2.04×10^{-3}	16.63×10^{-3}	78.3	62.7
20	4.37	3.70	2.59	23.87	84.7	68.5
21	4.71	4.29	2.85	28.57	91.2	74.4
22	4.19	3.88	2.40	29.85	92.5	78.8
23	4.32	3.29	2.48	22.70	76.1	68.0
24	3.93	1.89	2.52	11.45	48.0	33.4
25	4.94	3.89	2.89	27.80	78.9	64.8
26	4.32	3.66	2.48	25.25	84.8	70.2
27	4.64	4.07	2.67	23.95	87.9	70.4
28	4.44	3.52	2.55	22.00	79.4	62.5
29	4.49	2.96	2.58	17.42	66.0	50.6
30	4.12	1.61	2.37	10.07	39.2	27.2
31	3.99	2.97	2.30	17.47	74.6	58.4
32	3.36	2.75	1.92	21.15	81.9	69.0
33	4.40	3.78	2.52	29.10	83.3	72.6
34	4.57	3.49	2.61	26.85	76.5	64.1
35	3.93	2.36	2.25	15.23	60.2	46.7
36	4.07	1.31	2.33	8.46	32.2	21.3

TABLE IV (Continued)

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	$\mathcal{E}$ (per cent)
37	3.98×10^{-4}	3.13×10^{-4}	2.42×10^{-3}	12.51×10^{-3}	78.9	53.9
38	4.15	3.51	2.47	13.50	84.6	58.2
39	4.48	4.32	2.70	18.00	96.6	70.1
40	4.27	3.92	2.46	16.33	91.7	66.9
41	4.39	3.91	2.56	17.77	89.0	65.8
42	4.19	2.23	2.65	10.62	53.3	34.7
43	4.20	3.33	2.41	13.58	79.3	56.0
44	3.86	3.37	2.19	12.68	87.3	61.3
45	4.10	3.78	2.35	14.55	92.2	66.0
46	4.99	4.36	2.85	18.15	87.4	62.8
47	4.77	3.58	2.71	14.32	75.3	52.4
48	4.44	2.04	2.54	8.16	45.9	27.2
49	4.44	3.55	2.55	15.10	80.1	57.6
50	4.38	3.86	2.51	14.83	87.5	62.3
51	4.75	4.28	2.72	16.48	90.1	64.0
52	4.49	3.76	2.55	13.38	83.7	56.9
53	4.95	3.41	2.80	12.40	69.0	45.0
54	4.26	1.69	2.40	5.87	39.6	19.7

TABLE IV (Continued)

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	ε (per cent)
55	4.37×10^{-4}	3.90×10^{-4}	2.45×10^{03}	7.55×10^{-3}	89.3	42.9
56	4.03	3.78	2.24	7.04	94.0	44.8
57	4.27	4.22	2.39	7.84	99.0	48.0
58	4.77	4.70	2.67	8.92	98.6	48.8
59	4.34	4.18	2.40	7.65	96.2	46.2
60	4.56	3.78	2.57	7.03	82.9	36.8
61	4.44	3.98	2.50	7.81	89.5	43.5
62	4.00	3.76	2.26	7.16	94.0	45.3
63	4.66	4.58	2.63	8.73	98.2	48.4
64	4.61	4.24	2.60	8.08	92.1	43.9
65	4.28	4.00	2.39	7.41	93.5	44.1
66	4.35	2.84	2.45	5.41	65.2	25.2
67	4.08	3.69	2.30	7.03	90.5	42.8
68	4.64	4.35	2.61	8.53	91.1	46.5
69	4.61	4.46	2.58	8.27	96.7	46.6
70	4.76	4.59	2.68	8.74	96.5	47.1
71	4.12	3.60	2.32	6.86	89.2	40.9
72	4.72	2.66	2.66	4.79	56.5	17.3

TABLE IV (Continued)

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	$\mathcal{E}$ (per cent)
73	2.63×10^{-4}	2.00×10^{-4}	2.63×10^{-3}	11.43×10^{-3}	76.0	48.3
74	2.15	1.81	2.15	12.04	84.1	58.8
75	2.03	1.92	1.84	9.39	94.5	66.4
76	3.22	3.08	2.68	11.34	95.7	63.7
77	2.24	2.02	2.24	13.47	90.3	64.2
78	2.68	1.97	2.68	13.16	73.7	50.0
79	2.94	2.33	2.94	13.31	79.2	50.9
80	2.48	2.10	2.48	14.00	84.8	59.4
81	2.95	2.65	2.95	17.67	90.0	63.6
82	2.45	2.11	2.45	14.06	86.0	60.4
83	2.87	2.17	2.87	14.47	75.9	51.6
84	2.63	1.24	2.63	7.06	47.0	24.3
85	2.99	2.40	2.99	16.00	80.4	55.5
86	2.75	2.39	2.75	15.93	87.0	61.2
87	2.31	2.08	2.31	13.83	89.9	63.7
88	2.38	2.07	2.38	11.81	87.1	57.5
89	2.66	1.90	2.66	10.84	71.3	44.3
90	2.41	0.97	2.41	5.53	40.3	18.8

TABLE IV (Continued)

Dust Flow and Efficiency Results

Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	$\mathcal{E}$ (per cent)
91	3.58×10^{-4}	2.79×10^{-4}	2.65×10^{-3}	12.66×10^{-3}	77.7	51.4
92	3.27	2.79	2.42	12.68	85.4	57.8
93	3.34	3.17	2.49	15.09	94.9	66.6
94	4.00	3.56	2.98	16.91	89.0	61.9
95	3.03	2.74	2.26	13.04	90.6	63.2
96	2.06	1.14	1.53	5.45	55.6	33.7
97	3.08	2.39	2.28	10.86	77.8	51.5
98	2.30	1.91	1.70	8.67	83.0	55.9
99	2.82	2.57	2.09	11.68	91.4	62.6
100	3.19	2.80	2.36	12.72	87.9	59.9
101	3.53	2.63	2.61	11.95	74.5	48.7
102	3.56	1.59	2.64	7.23	44.6	23.8
103	2.96	2.31	2.19	10.47	77.9	51.6
104	3.43	2.84	2.54	12.91	82.8	55.8
105	3.00	2.74	2.22	12.42	91.4	62.9
106	3.05	2.54	2.26	11.54	83.1	56.2
107	3.19	2.13	2.36	9.67	66.7	42.3
108	2.84	1.13	2.10	5.12	39.7	19.6

TABLE IV (Continued)

Dust Flow and Efficiency Results

Run Number	G_1 (lb./sec.)	G_2 (lb./sec.)	C_1 (lb./lb.)	C_2 (lb./lb.)	G_2/G_1 (per cent)	$\mathcal{E}$ (per cent)
109	4.54×10^{-4}	3.61×10^{-4}	2.43×10^{-3}	12.90×10^{-3}	79.5	55.0
110	4.17	3.56	2.22	12.71	85.3	60.0
111	5.19	4.76	2.66	16.60	91.8	65.5
112	4.66	4.31	2.38	15.02	92.5	66.4
113	5.11	4.52	2.62	15.74	88.5	62.6
114	4.90	2.85	2.61	10.18	58.2	36.9
115	3.80	3.04	1.95	10.57	79.8	55.4
116	4.20	3.66	2.15	12.75	87.1	61.8
117	4.70	4.30	2.41	15.00	91.5	65.5
118	4.87	4.39	2.50	15.30	90.2	64.5
119	4.24	3.23	2.18	11.26	76.4	52.5
120	5.06	2.35	2.60	8.19	46.4	27.1
121	4.88	3.79	2.51	13.21	77.7	53.5
122	5.04	4.22	2.58	14.67	83.7	58.6
123	4.84	4.45	2.48	15.47	91.9	65.6
124	4.18	3.47	2.14	12.08	83.0	58.2
125	3.86	2.60	1.98	9.04	67.4	44.7
126	4.12	1.62	2.11	5.63	39.2	20.9

APPENDIX C

PROOF

PROOF

Statement of the Problem

What cone has a circular cross-section that varies with distance (height) approximately as the variation of cross-section with distance of a given right prism; the base areas of cone and prism to be equal?

Proof

The cross-sectional area of a cone at any point, x, is:

$$(1) \qquad A_c = \pi r^2 ,$$

where $r = f(x)$

and when $x = 0,\ r = R$

$x = L_c,\ r = 0$

therefore,

$$(2) \qquad (r - R) = \frac{R}{L_c}(x - 0)$$

or $r = R - \frac{R}{L_c} x$

substituting,

$$(3) \qquad A_c = \pi \left[R - \frac{R}{L_c} x\right]^2$$

The cross-sectional area of the prism is

$$(4) \qquad A_p = Cy$$

where C is the depth of the prism (in the two-dimensional separator used in this study $C = 2$ inches), and

$$y = f(x)$$

when $x = 0,\ y = Y$

$$x = L_p,\ y = 0$$

therefore,

$$y = Y - \frac{Y}{L_p} x \tag{5}$$

substituting,

$$A_p = C\left[Y - \frac{Y}{L_p} x\right] \tag{6}$$

The rate of change of area with distance is the first derivative with respect to x.

$$\frac{dA_c}{dx} = 2\pi\left[R - \frac{R}{L_c} x\right]\left[-\frac{R}{L_c}\right] \tag{7}$$

$$\frac{dA_p}{dx} = -C\frac{Y}{L_p} \tag{8}$$

At $x = 0$,

$$A_p = A_c$$

therefore

$$\pi R^2 = CY$$

$$Y = \frac{\pi R^2}{C} \tag{10}$$

Substituting (10) into (8),

$$\frac{dA_p}{dx} = - C \frac{\pi R^2}{CL_p} = - \frac{\pi R^2}{L_p} \tag{11}$$

Equating first derivatives,

$$\frac{dA_p}{dx} = \frac{dA_c}{dx} \tag{12}$$

$$\frac{\pi R^2}{L_p} = - 2\pi \left[1 - \frac{x}{L_c}\right] \frac{R^2}{L_c}$$

we have

$$\frac{L_c}{L_p} = 2 \left[1 - \frac{x}{L_c}\right] \tag{13}$$

also

$$A_c = \pi R^2 \left[1 - \frac{x}{L_c}\right] \tag{3}$$

solving simultaneously,

$$\frac{L_c}{L_p} = 2 \frac{A_c}{\pi R^2} \tag{14}$$

and substituting the boundary value

$$A_c = \pi R^2$$

$$\frac{L_c}{L_p} = 2 \tag{15}$$

and the height of the cone is shown to be twice the height of the prism.

APPENDIX D

CALIBRATION OF ORIFICE METERS

CALIBRATION OF ORIFICE METERS

The orifices used to meter the air flow in this study were designed and calibrated on information contained in an A.S.M.E. Research Committee Report on Fluid Meters.[21] Flange pressure taps were used for all orifices. These were located one inch upstream and one inch downstream from the respective faces of the orifice. Rubber gaskets 1/16 inch thick were used between the orifice plates and the pipe flanges.

The sizes of the three orifices were determined by estimating the maximum flow through each, and then arbitrarily selecting a maximum pressure differential across each orifice.

The flow equation for thin plate orifices is

$$w = 0.0997 \frac{CD_2^2}{\sqrt{1 - \beta^4}} \sqrt{\rho_1 h}$$

where

w = Flow rate - lb./sec.

C = Coefficient of discharge

D_2 = Diameter of orifice - inches

$\beta = D_2/D_1$

D_1 = Pipe diameter - inches

ρ_1 = Air density - lb./cu.ft.

h = Orifice pressure differential - inches water.

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[21] American Society of Mechanical Engineers, Fluid Meters, Their Theory and Application, Part 1, The American Society of Mechanical Engineers, New York, 1937.

The term $1/\sqrt{1-\beta^4}$ is a velocity of approach correction, and $K = \frac{C}{\sqrt{1-\beta^4}}$ is called the flow coefficient.

Tables of flow coefficients are included in the Appendix of the Fluid Meters Report.[22] They are given as a function of β, and Reynold's Number for different pipe sizes, and for various pressure tap arrangements.

The sizes of the orifices, as determined by trial solutions of the orifice equation, were:

Orifice	1	2	3
Pipe Diameter	3"	3"	1-1/2"
β	0.650	0.700	0.700
Orifice Diameter	1.995"	2.1476"	1.127"

The flow coefficients for these orifices were plotted against Reynold's Number to eliminate the necessity of interpolating in the tables. The curves are included in this thesis as Figures 31, 32, and 33.

The blowdown air meter and the clean air meter were both calibrated against the total air flow meter. The clean air meter was calibrated by closing the blowdown valve completely so that the flow through orifice 3 was the same as through orifice 1. The blowdown meter was calibrated by taking differences between total air flow and clean air flow; see Table V. The flow through orifice 1 was calculated with the

[22] Ibid.

thin plate orifice equation, and the curve, Figure 31. The flow was also calculated for orifice 2, and for orifice 3, by the same method, but only as a check on the accuracy of the instrumentation, and not to determine the flow in the test runs. The maximum variation in agreement did not exceed four percent. The calibration curves, Figures 34 and 35, were used to determine the various flow rates for all the test runs.

TABLE V

Calibration of Orifice Meters

Barometer = 29.08 in. Hg. Dry Bulb Temp. = 86 F

Gas Constant, R, = 53.9 ft.-lb./lb. F Wet Bulb Temp. = 75 F

Run	T_s (F)	h_s (in. H_2O)	h_1 (in. H_2O)	h_2 (in. H_2O)	h_3 (in. H_2O)	W_1 (lb./sec.)	W_2 (lb./sec.)	W_3 (lb./sec.)
1	103	8.8	1.2	0.9	0	0.0778	0.0778	0
2	103	12.7	1.8	1.4	0	0.0954	0.0954	0
3	103	17.5	2.8	2.1	0	0.1197	0.1197	0
4	102	22.8	4.0	2.9	0	0.1435	0.1435	0
5	102	27.6	5.0	3.6	0	0.1610	0.1610	0
6	102	28.8	5.2	3.8	0	0.1645	0.1645	0
7	101	31.2	5.6	4.0	0	0.1716	0.1716	0
8	104	28.8	6.2	3.5	0.5	0.1795	0.1595	0.0200
9	104	27.8	6.6	3.2	1.4	0.1845	0.1525	0.0325
10	104	27.0	7.0	3.0	2.6	0.1908	0.1468	0.0440
11	104	25.9	7.4	2.7	5.1	0.1950	0.1395	0.0555